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PROJECT COST ESTIMATION IN THE SALES PHASE: IMPLEMENTING PROJECT UNCERTAINTY ESTIMATION PRACTICES

Master's Thesis

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ABSTRACT

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There is an endless list of management horror stories, and it is called a list of projects that overrun their original cost estimate. There are plenty of examples of overrun projects from the wide variety of different industries, and there is no evidence that developments in project simulation models or utilisation of data are going to solve the fundamental difficulty of cost estimation in the near future. In fact, there seems to be a significant gap between the complex algorithms and estimation methods that currently exist in the literature and methods that the companies actually use for cost estimation.

The objective of this thesis is therefore to advance knowledge about communicating and sense making of uncertainty in the project cost estimation phase. This is done by exploring implications and changes that the implementation of uncertainty estimation practises causes in the case company of this thesis. Uncertainty estimation for project front-end, in the sales phase, was something new for the case company. The implementation was therefore very rare opportunity to witness a situation where organization has realized that they are unable to correctly manage and estimate the uncertainty that is present in their project environment.

Findings of this thesis suggest that it is beneficiary to include multiple organizational functions into the estimation process and translate their analyses and feelings about uncertainty into boundary object, through which uncertainty can be communicated. In this thesis boundary object was cost contingency, which concretized for the organization that uncertainty has inevitable cost implications for the project. Through this communication organization can form organizational view on uncertainty of the project, instead of all the different organizational units trying to analyze and manage the uncertainty separately.

PREFACE

Deep down in my hearth, I am humanist who just happened to study engineering. This meant that, when presented with the opportunity to improve project cost management of my case company, I was not only interested about the technical side of the cost estimation. I wanted to understand what happens in the organization and in the minds of people when they estimate uncertainty. Main learning for me from this process is that humans are very bad at understanding and estimating something as vague as "uncertainty", and therefore its management requires both communication and better data.

Research process began in September 2017 and was finalized in April 2018. I am thankful for the case company and my supervisor there to be able to concentrate on this thesis and the intervention I executed for the case company. Without my supervisor in the case company and wonderful feedback from the project and sales managers, this thesis would have been even more separated from the practicalities of the project management.

In addition to the case company, I want to thank Dr. Jouni Lyly-Yrjänäinen for his feedback and guidance; both his courses and the feedback I received for this thesis have been eye-openers on how hard it is to produce knowledge and to keep your writing logical and consistent. This thesis is nowhere near perfection, but everyone has to start somewhere, and I will surely return to the teachings of this thesis whenever I'm starting complicated writing tasks in the future. Last but not least, I would like to thank all the friends and loved ones I have met during my studies, for this would have been a boring journey without you.

Helsinki, 18.4.2018

Teemu Viljamäki

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LIST OF TERMS AND ABBREVIATIONS

AC	Actual costs, Actual realized costs related to project/activity
BAC	Budget at Completion, Estimated budget at project completion
COGS	Cost of goods sold
Contingency	Cost item used as a buffer for risks and to communicate risk information
CPI	Cost Performance Index, EV/AC
ERP	Enterprise resource planning system, system that is used to integrate and contain information from the different activities of the company
EV	Earned Value, Actual value earned so far during project/activity execution
PIC	Product inventory price, price that it takes to produce finalized product to the inventory
PV	Planned Value, the cost/schedule value that was given to activity at the project estimation stage
R&D	Research and development
RFQ	Request for Quote
SPI	Schedule Performance Index, EV/PV
Turn-key	Project in which the provider takes the full responsibility for the implementation and delivery of the project

1. INTRODUCTION

1.1 Background

Large projects are often characterized by significant cost and time overruns (Shane et al. 2009, Giezen 2012, Merrow et al. 1981). Historically especially construction projects and transportation infrastructure projects have been plagued by cost escalations (Shane et al. 2009); for example Flyvbjerg (2014) estimates that 9 out of 10 transportation infrastructure projects exceeded their initial cost estimate, and in another study Lee (2008) found out that out of 138 evaluated road projects 95% had exceeded their budget. However, examples are easy enough to find almost in any other industry as well, such as IT (Brooks 1995) or energy industry (Engwall 2003). The worst of these cost escalations also make it to the newspapers and media regularly since these projects are often funded by the public money and hence also gather interest of taxpayers.

Even though big part of the literature on cost overruns focuses on the major projects, it is not the sheer size of these projects that causes overruns and cost escalations, but rather the complexity and uniqueness of the projects (Merrow et al. 1981). Perceived reasons for cost overruns vary from poor project management to poor communication between stakeholders (Jackson 2002), but one recurring theme related to the project overruns seems to be high degree of uncertainty in the planning phase – which then later in the project results in budget difficulties.

In this sense, the overruns are often failures of uncertainty management and inability to respond to uncertainty in the project environment. Some uncertainties can be predicted and therefore mitigated at the beginning of the project, while others are difficult or impossible to foresee and therefore create uncertainty into the project implementation phase (Atkinson et al. 2006). Traditional project literature emphasizes the control procedures as means to mitigate the risks, but this approach is often criticized by its inefficiency into responding uncertainty (Atkinson et al. 2006). This thesis acknowledges the same fact, and instead of trying to perfectly model the project environment and its every detail, the goal is to increase the understanding project stakeholders have about the project uncertainties, so necessary actions can be taken to manage uncertainty.

This thesis was conducted for the case company between September 2017 and April 2018. Case company has a long history of delivering projects, but the size and complexity of them was increasing significantly. Projects of the case company are typically delivered to different countries and to completely different types of project environments for example

in the terms of culture, customer know-how and legislation, making reliance completely on historical data difficult. Furthermore, often the case company is also responsible for the overall execution of the project, as the projects are sold as turn-key deliveries for the customer, meaning that the responsibility of uncertainty management was completely case company's responsibility as a turn-key supplier.

This thesis is a case research on how uncertainty estimation practices and the culture of analyzing uncertainty can be adopted into a company that has not experiences over them. Furthermore, how different stakeholders in the company make sense of uncertainty for cost estimation practices was also a key interest in this research. Useful concept in this was treating uncertainty analysis as a boundary object through which different organizational functions, especially sales and project management, can communicate about their views and understanding about uncertainty.

1.2 Objectives and Scope

Söderlund (2011) advices that future research in the field of project management should embrace the pluralism of project management research and use multi-perspective approach to further advance the field. More precisely, Söderlund and Maylor (2012) found that there is a research gap between the "hard and soft sides" of project management. However, in real life project managers must deal with both hard side and soft sides of project management simultaneously (Koppenjan et al. 2011). Therefore, this thesis aims to mix these hard and soft sides of project management by both researching implementation of control and analysis methods for uncertainty and the communication and understanding that arises from the usage of those methods.

Akintoye (2000) commented in conclusions of his study that the future research on project cost estimation should focus further on the cognitive aspects of estimation practices, rather than just taking a look into estimation principles. Agreeing with this, Williams and Samset (2010) discussed about how the psychology and biases affect the cost estimation practices. They recognized a precise research gap:

> *"There is a need for further research into how different organizational forms and cultures with different project complexities and domains operate in all of these stages and the correlations between them."*

In a similar manner, Turkulainen et al. (2013) addressed the need to further research organizational integration mechanisms:

> *"Very interesting, yet empirically rather challenging, would be to assess the use of integration mechanisms in project-based firms and their global projects from*

> *an institutional perspective…one way to empirically address the institutional perspective would be by closely observing the actual decision making processes in the firms."*

When looking more closely the literature on uncertainty management, there is a research gap between different types of uncertainty and practical ways to manage them. For example, Saunders et al. (2015) conclude in their article on uncertainty that there is a research gap between linking different determinants of uncertainty to the different approaches to manage them. In similar manner, Sauser et al. (2009) found out that in project management literature there is a need to find out what kind of methods fit into what situations.

This thesis follows these authors' call for research and builds its research on the case study of practically implementing uncertainty management practices. This offers interesting research approach through which it can be demonstrated how the uncertainty analysis can practically support the decision making and communication between different organizational cultures and different departments of the organization, compared to the situation where the uncertainty has not yet been conceptualized in the active usage at the case company.

There are not many previous case studies done from the implementation of uncertainty management practices. For example, the seven schools of project management Söderlund (2011) recognizes are mainly interested about different methods of managing project and their uncertainty and none of them is mainly focused on implementing new project management methods. There is a wide branch of literature in implementing for example activity based costing models (see for example Anderson 1995) and lean models (Pheng & Teo 2004, Kumar et al. 2006), but these do not necessarily concern the project management or project uncertainty management literature. Furthermore, in many studies where the risk management or uncertainty management practices are implemented (Conrow & Shishido 1997, Rice et al. 2008), the main focus still remains on details of the tools itself instead of their impacts on daily practices, communication, culture and generally soft side of project management.

This lack of case studies where the uncertainty management practices are implemented means that the case study conducted for the case company is interesting as such, as literature scarce about the organizational implications of different uncertainty management models. This also offers a good chance to combine different schools of project management and therefore embrace pluralism as Söderlund (2011) recommends. Last but not least, this thesis offers more insight into the important organizational boundary between project and sales functions.

The objective of this thesis can now be stated as…

> *….. to investigate, how organizations estimate, make sense and communicate uncertainty and its costs in the project sales phase.*

In more detail this objective is reached with the help of three supportive objectives. Firstly (1), this thesis aims to find out on concrete level, what kind of tools are used to estimate uncertainty in Finnish project-based industries. Secondly (2), in this thesis the intervention for the case company's uncertainty estimation practices is made, and those impacts for the company that does not have previous experience about estimating uncertainty are observed. Finally (3), by comparing the literature and observations from the case study, we evaluate how uncertainty estimation tools can enhance understanding and communication about project uncertainty in the project sales phase.

Aim to find out what tools are in use in Finnish project-based industries is rooted to the traditional project management practice where the focus is in the usage of tools and quantitative modelling of projects. Söderlund (2011) defines this as optimization school of project management. However, this objective also links the research into ongoing practice in the uncertainty management; rather than analyzing advanced concepts for uncertainty analyses that can be found from the literature, this thesis focuses specifically on the existing practices.

However, rest of the study is more rooted to the behaviorist schools of project management, in which the focus is in organizational processes, knowledge management and communication (Söderlund 2011). The goal is to observe the changes on the behavior and practices in the case company to understand what effects the concept of uncertainty causes in the behavior of project and sales management and what kind of communication the uncertainty analysis enables.

Finally, the whole topic of the thesis is closely related to the decision school of project management, which is interested about the decision making of the projects which lead to project's approval or cancellation (Söderlund 2011). This is due the fact that uncertainty analyses are used for supporting decision making processes in the project front-end (Garvey et al. 2016); for example, in the ideal situation the projects in which risks and cost are unacceptable should be cancelled before they even progress to the implementation phase.

1.3 Structure of the thesis

There are nine chapters in this thesis. Chapter 2 aims to portray a process of the thesis work and presents research's methodology choices. This chapter also takes a deeper look into explaining interventionist approach used in this thesis and the usage of semi-structured interviews in this research.

Chapters 3 contains literature review to the field of uncertainty management, looking into how literature currently defines uncertainty, what different schools of thoughts there is regarding uncertainty management and finally presenting, how different individuals and organizations have different perceptions on uncertainty.

Chapter 4 takes a literature review on the practical side of this thesis, which is project cost estimation. After this, chapter presents current practices found in the literature which can be used to analyze uncertainty in a project cost estimation phase.

Chapter 5 contains pivotal concept for this thesis, boundary objects, and uncertainty analyses are in this chapter analyzed as boundary objects through which different organizational functions can communicate their perception of uncertainty.

Chapter 6 presents the case company, business processes relevant to the thesis topic and current situation that the company faces. After this, analysis of the current understanding and the management of uncertainty in the case company is presented based on the researcher's interactions and observations in the case company during the beginning part of the intervention.

Chapter 7 presents the interventions done in the case company. At the beginning of the chapter findings from the external interviews are presented, drawing picture about practices in use in different industries regarding uncertainty estimation and management in the cost estimation phase.

Chapter 8 continues this theme by analyzing intervention's effects at the case company, how the processes and communication in the case company changed and analyzes what this means from the perspective of this thesis framework.

Finally, chapter 9 evaluates how the goal of the thesis was reached, assesses the implications on research and managerial practice and analyzes the limitations of this study.

2. RESEARCH PROCESS AND STRATEGY

2.1 Research process

Research process started with recognizing the broad problem of cost overruns with the case company at the beginning of September 2017. Case company had recognized that they were not meeting the designed project budgets, and from the case company's perspective the aim was to find proposals and concrete solutions how the profitability of the projects could be improved. This meant that it was beneficial for the researcher to use interventions as data gathering methods, as some kind of change or improvement in the project delivery process was what the case company desired.

There had been significant amount of "lessons learnt" type of exercises in the case company in the past, and the mistakes and failures that occurred in the past projects were well known. It was clear that there was little to be learned from benchmarking the past practices. Project cost estimation practices at the case company were really straightforward and deterministic, and based on an assumption that everything will go according to the original estimate. Lack of uncertainty estimation in the case company lead to the risk that projects were sold with wrong margins, and that case company started projects with unrealistic cost estimates. This made educated decisions regarding uncertainty and desired sales price difficult in the case company.

Therefore, the main focus of this thesis soon switched on to how the uncertainty estimation practices can be introduced to the case company's processes. For the research this offered an interesting outlook on about what cultural changes this enabled and what kind of communication emerged in the case company when the uncertainty was defined and analyzed. Approach in this thesis was to seek good practices for project cost estimation process, introduce them in the case company and then observe as a researcher the changes and effects these concepts had in the case company.

Project started by interviewing internally case company's management, project managers, sales managers, and other persons related to the case company's project sales and delivery process. The goal was to better scope the project and recognize potential for improvements in the process that could be meaningfully implemented by the researcher.

Literature review was conducted from the very beginning to establish background and framework against which findings could be evaluated. Literature review was necessary from two viewpoints. Firstly, to recognize what the literature says about the best practices of controlling project costs, so that the intervention could be planned. Secondly, as in any

research, literature review was necessary for recognizing the gaps in the project cost management literature, so that the findings could be looked in a way that this thesis advances the existing project cost management literature.

During this beginning phase of the thesis work the cost estimation process was recognized as having most potential for the improvement, as the current cost estimation practices did not seem to take account the uncertainty in a systematic way. Furthermore, the views and tools among project function and sales function about uncertainty in their estimates varied a lot, which then seemed to offer interesting topic for the thesis, as there was not previous research in which the project cost estimation tools would have been analyzed as boundary objects.

Intervention itself consisted of two parts: interviews and implementation of the uncertainty estimation tool. Goal of the interviews was to benchmark best practices and tools in use in the five Finnish project-based companies for the case company. Case company could have done this themselves had they decided to do so, and the questions asked in benchmarked companies were not particularly scientific: researcher provided here raw manpower and time to go in the field and ask about the estimation practices. Second part of the intervention was then to implement a tool for estimating the effect of uncertainty on the project cost estimates, based on the information found from the project management literature and from the benchmarked external companies. This tool was also implemented to the case company's processes and trained for project managers and sales managers. These training sessions then provided invaluable feedback and allowed the researcher to see in practice the effect of the implemented tools on ongoing projects.

Finally, the findings from these activities were analyzed against the existing literature and the objective of this thesis. Timeline of these activities is presented in Table 1.

Table 1. Research process.

Activities	2017				2018		
	September	October	November	December	January	February	March
Gathering understanding on case company's cost estimation process	Chapter 6						
Literature review	Chapters 3-5						
Building framework						Chapter 5.2	
External interviews				Chapter 7.1			
Building tool for uncertainty estimation					Chapter 7.2 - 7.5		
Implementing uncertainty estimation practises in the case company							Chapter 7.2, Chapter 8
Writing lesson's learnt							

As quite often happens when using intervention as a data-gathering method, the overall process for intervention from this initial starting point proved to be very iterative in nature (Saunders et al. 2011). In the process for crafting the intervention, four iterative loops of diagnosis, planning of the activities, action and result evaluation can be recognized. These are presented in Figure 1.

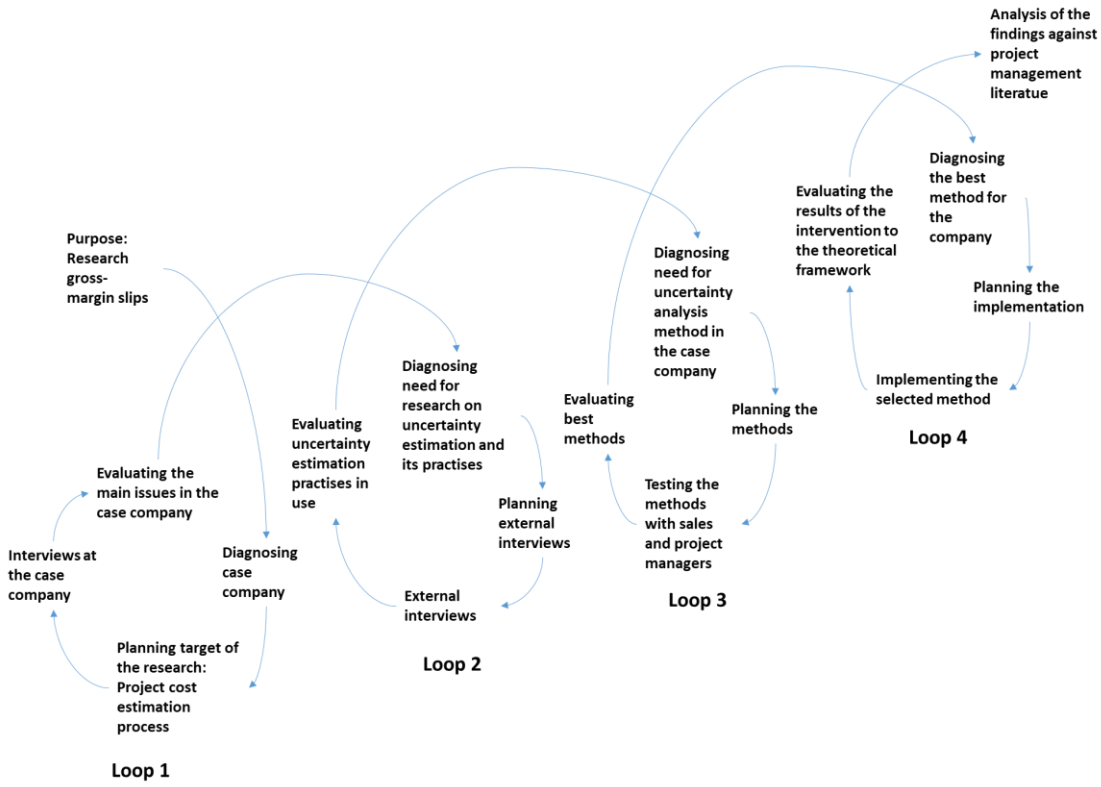


Figure 1. Iterative nature of the intervention.

Interviews at the case company were the first loop, which led to conclusion that there is a need to focus on cost estimation phase and that it is necessary to find options for the actual uncertainty estimation. Second loop were the external interviews, which led to the list of options and gave practical feedback about different uncertainty estimation methods. Third loop was testing the methods at the case company in order to select the most suitable uncertainty estimation method. Finally, the method was implemented, which provided more feedback and knowledge about the practical usage of the implemented method.

Implementation in itself was already interesting, as the examples from implementing uncertainty analysis tools for project business are rare. Furthermore, the findings from these activities were analyzed against the framework constructed with the literature review and recognized research gaps. Framework aimed to explain how the understanding of the uncertainties in the project environment can be communicated across organizational functions with the help of boundary object. Used framework will be presented at the end of the literature review in chapter 5.

2.2 Research philosophy and methodology choices

Purpose of this research is exploratory. It aims to set new insights into how organizational boundaries affect the uncertainty estimation practices and to the understanding over uncertainty. At the same time, this thesis aims see different ways in which uncertainty analysis is linked to the organizational communication. This purpose of the research affected

the methodology choices of this thesis, which are summarized in Figure 2 by adapting the "research onion" as presented by Saunders et al. (2011).

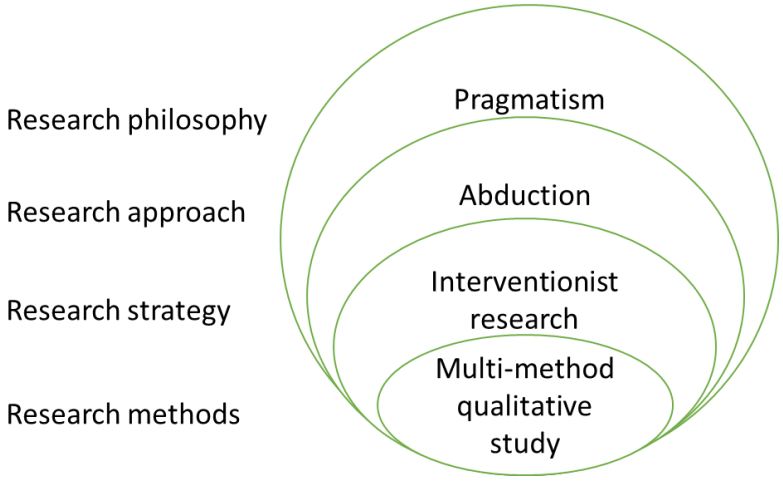


Figure 2. Research choices of this thesis (adapted from Saunders et al. 2011).

Research philosophy is a broad concept encompassing the development and the nature of knowledge (Saunders et al. 2011). Research philosophy adopted in this thesis is pragmatism, which can be described as approach in where the reality is interpreted in the way which best supports and enables answering to the research question (Saunders et al. 2011). Johnson and Onwuegbuzie (2004) describe characteristic view of pragmatism as "knowledge is both constructed and based on the reality of the world we experience and live in". This describes well the situation and the topic of this thesis: while uncertainties and project risks are real life events, they are also interpreted, managed and even caused by psychological and organizational factors.

Cost estimation is sometimes seen as very positivist process by its practioners, in which the researcher aims to keep the research free of value and analyze the reality in deterministic way. In this kind of approach the focus is in quantifiable observations and the assumption is that they reveal true knowledge about reality (Saunders et al. 2011). On the other hand, when dealing with unknowns of the estimation more interpretivist approach is required and it is necessary to understand the subjective nature of human and organizational interactions. Therefore, in the context of this thesis it was necessary to look both objectively at the available data and the meanings attached to it by individuals.

Saunders et al. (2011) define induction and deduction as two main research approaches. Deduction can be understood as the search of causal relationships between variables: research aims to test the theory in practice. Induction takes the opposite approach: data is first collected and then analyzed. (Saunders et al. 2011) Research approach in this thesis was abduction, which can be understood as combination between inductive and deductive approaches (Dubois & Gadde 2002). Abduction is a typical approach in interventionist studies because the intervention often requires the balancing between emic and etic levels of research: emic meaning the study of human behavior as a part of the system, and etic

outside it (Suomala et al. 2014). Emic viewpoint therefore often requires inductive approach, whereas on the etic level deductive approach is often used.

Research strategy in this thesis can be best described as interventionist research. Interventionism as used in this thesis is synonym with what Saunders et al. (2011) define as action research. In this thesis term "interventionist research" is preferred over "action research". Saunders et al. (2011) note the lack of clear definition of interventionist research, noting that there are several elements associated with the term in the literature. These elements are

1. Goal of causing change the case organization
2. Active participation of researcher into the case organization's activities
3. Iterative nature of research
4. Implications beyond imminent research project

First and second points are what according to Suomala et al. (2014) separates interventionist research from the empirical case studies; although in the empirical case studies interviews and observations are often the main data gathering methods, in interventionist research the researcher is "a facilitator of change". Interventionist research is therefore typically concerned about solving problems or issues in the target organization and aims for the change in the environment. Furthermore, interventionist research includes the involvement of researcher in the organization where the problem-solving takes place.

Thirdly, as Saunders et al. (2011) note, interventionist research is iterative process, during which diagnose, planning, action taking and evaluation happens in multiple cycles. This is because in most cases the researcher does not know what data the intervention will reveal or the findings that can be derived from the data. In this sense interventionist researcher is a detective who analyses the facts revealed by the subsequent cycles of action taking and diagnosing, with the exception that the interventionist research might not always know what they are looking for.

Finally, the interventionist research should have implications beyond the research project and ideally advance and develop theories and knowledge (Saunders et al. 2011). As Suomala, et al. (2014) note, one of the dangers of interventionist research is the unpredictability of obtaining academically interesting results. As the researcher ventures in the case company, they do not know before the intervention what findings they will make and whether they will uncover anything interesting. From this point of view interventionist research is a bit like gambling; there is a possibility of gaining unique access to the case company and uncovering truly interesting phenomenon that would not have been encountered through questionnaires or interviews, but at the same time there's a risk that this access does not reveal anything academically interesting.

Multi-method means research which applies multiple techniques to the collection of data and analysis but in which the methods are either from qualitative or quantitative domain

(Saunders et al. 2011). Despite from acknowledging both positivist and interpretivist research philosophies through the lenses of pragmatism, this thesis uses mainly qualitative techniques and can therefore be described as qualitative multi-method study. Quantitative methods were used during the intervention to affect cost estimation process of the case company, but this was not data gathering for the research purposes.

2.3 Data-gathering methods

Gummesson (1993) listed data-gathering methods of the qualitative research to be as follows: 1) Using existing material, 2) Questionnaires and surveys, 3) Interviews, 4) Observation and 5) Action research. Table 2 summarizes how these different methods were used in the course of the research.

Table 2. Data sources of the research and their purpose in the data gathering.

Category	Form of usage in this thesis	Purpose
Use of existing material	Literature review	-Familiarization with existing theories -Positioning the study -Ideas from the ways in which company's processes could be improved
	Project reports	-Familiarization with the problems of the case company's projects -Researching cost overruns and their causes at the case company
Interviews	External semi-structured interviews	-Mapping best practices -Positioning the research questions to the wider context
	Internal semi-structured interviews	-Understanding the uncertainty in the activities of the case company
Observation	Observation in the company	-Understanding the context and the culture in the case company
Action research	Intervention	-Understanding the process of current cost estimation and uncertainty management practices -Observation of changes in the company and its practical limitations

Use of multiple data sources and methods increases triangulation of the study and therefore the reliability of the study (Barratt et al. 2011). Despite the usage of most of the data gathering methods Gummesson (1993) mentions, main data gathering method was intervention and semi-structured interviews. Semi-structured interviews allowed to understand the current practices at the case company and to research the cost estimation practices in other industries. After this, the intervention provided access to first-hand information by disturbing the communication and the cost estimation practice at the case company, and allowed to focus on answering the main research questions.

According to Saunders et al. (2011), in a semi-structured interview researcher has a list of themes and questions prepared for the interview, but they may be developed and modified for each interview according to the context and the progress of the interview. Semi-structured interview offers for the interviewees and interviewer greater degree of freedom to where to direct the conversation (Saunders et al. 2011), and hence the opportunity to open discussion about issues neither has considered before.

The use of probes is typical for the semi-structured interviews. Probes, also known as follow-ups, are way to stimulate the interview and to get additional information during the course of the interview. Typical situations are when the interviewer does not understand everything the interviewee has said, or believes that the respondent could be able to answer in more detail and depth. (Harrell & Bradley 2009) Probes are therefore used to clarify what interviewee has said or for increasing the completeness of interviewees accounts. According to Saunders et al. (2011) the use of probes is typical when adopting interpretivist approach and trying to understand the meanings interviewees attach to their answers. Finally, probing may lead the researcher into the discussion that includes a viewpoint not originally considered while planning the research but which is important for the overall understanding of the research subject (Saunders et al. 2011). Probing can also cause biases into the research, for example in situations where interviewee says things that are not true because they lack knowledge or they just want to satisfy the researcher (Harrell & Bradley 2009).

Saunders et al. (2011) list some situations where the usage of semi-structured interviews can be advantageous. Usage of semi-structured interviews is typical or the explanatory and exploratory studies when the rich data over causal relationships or new phenomena is needed. Interviews are also used a lot when there is a need to establish a personal contact with the interviewee, either in order to gain access to them or to get them confident in revealing the details about their practices. Furthermore, semi-structured interviews are suitable for situations where the questions are large or open-ended. Finally, semi-structured interviews allow the interviewees to control the time they spend for the interviews. The reasoning to use semi-structured interviews in this thesis is presented in Table 3.

Table 3. Reasoning for using semi-structured interviews.

Reason to use semi-structured interview	Reasoning in the context of this study
Purpose of the research	This study was exploratory and explanatory
Significance of personal contact	The study involved gaining access to information about company processes; it was necessary to sell the idea of interview to the interviewees
Nature of questions	Course of interview was hard to predict due to high variance in the uncertainty management practices in different companies
Length of time required	Interview was more suitable for participants than the questionnaire, since then the interviewees had more control over time spend on the interview

Gummesson (1993) sees interventionist research as data gathering method in itself which can then involve other data gathering methods. Intervention as a research method allowed access to the host organization. While data from the uncertainty management tools could have been obtained from the literature, the data about their practical usages and organizational issues could not have been obtained by simply interviewing the host organization. Most notably, the host organization would not have adopted uncertainty management practices without participation of the researcher, and therefore this disruption in the case company could not have been analyzed.

Intervention as a research method allowed to immediately test the ideas "on the field" (Suomala et al. 2014) and to get data from the practical impacts of the uncertainty estimation practices. This allowed movement between the academic ideas and the practical project management (Jönsson & Lukka 2005). This was very suitable for the research gaps at hand since many of these arose from the literature's notion that there is a gap between understanding the practical side of uncertainty estimation and the theory of uncertainty. However, this active participation posed also challenges for the research, as it was possible, like mentioned by Suomala and Lyly-Yrjänäinen (2012) to create idiosyncratic results that would not have been encountered otherwise.

During this thesis the role of the researcher towards the company was more or less a consultant whose aim was to improve profitability of case company's projects by improving the way uncertainties are calculated in the sales phase. This enabled close participation in the case company's cost estimation processes as well as access to all the data related to it. Drawback was that not all the work that was done directly contributed to this thesis as several work phases and analysis made were only interesting from the case company's viewpoint. However, it can be argued that this in turn increased the researchers understanding on case company's activities, and trying to eliminate all of this excess work would have been counterproductive for the results of this thesis, as it would have decreased both the value to the case company and the understanding of the researcher of the project uncertainties.

3. PROJECT UNCERTAINTY

3.1 Uncertainty

PMI (2008) defines the project risk as “an uncertain event or condition that, if it occurs, has a positive or negative effect on a project's objectives”. Even though this definition includes both positive and negative consequences, the word “risk” has inherently negative connotation in it. Given the fact that many projects are struggling with cost overruns (Flyvbjerg et al. 2014), it is not much of a surprise that traditionally the negative side of effects has been emphasized and much of the attention has been on mitigating the negative effects and less about managing positive opportunities (Ward & Chapman 2003).

In mathematical terms the “risk” is often broken down into the multiplication of probability and impact (Williams 1996). While defining and managing risks this way surely helps to evaluate the severity of risks, it draws very deterministic picture on the nature of risk and contains the idea that the risk is something that can accurately be quantified before the project. While this might be possible regarding simple projects or in situations where there is plenty of accurate historical data available, often in reality it is impossible to measure all the risks or even try to acquire and process all the information related to the complexities of the project. Project managers and humans in general make assumptions based on previous experience and knowledge, and while this is relevant in regular situations, in unique situations this means that future cannot be predicted accurately (Taleb 2007). Following example of Ward and Chapman (2003), in this thesis the term “uncertainty” is preferred over the term “risk” to emphasize on the one hand the unpredictable nature of reality and on the one hand the possible non-predictable positive events that might happen as well.

Van der Hejden (2011) recognizes 3 categories for uncertainty: Risks, structural uncertainties and unknowables. Similarly, De Meyer et al. (2002) categorize uncertainty into four categories: variation, foreseen uncertainty, unforeseen uncertainty and chaos. In this thesis taxonomy of De Meyer et al. (2002) is preferred due convenient and descriptive naming, but the fourth category, chaos, is left out. This is due the fact the fourth category of De Meyer et al. (2002), chaos, refers to projects where even the outcome is completely uncertain, in an extent for such projects the outcome might be completely different from the project’s original intent. This might happen for example when a software developed as a game turns out to have practical appliances. Whereas chaos is useful concept for example in the software development, the concrete nature of the projects under observation in this thesis did not allow projects where chaos was encountered.

Variation refers to minor adjustments in the values of pre-known activities of which organization possesses enough historical pretext for example in the form of similar events,

so probabilities for various outcomes can be reasonably estimated. Structural uncertainties are events, which can be predicted through cause and effect chain of reasoning, but organization have no means of assessing how likely it would be. Unknowables, "Unknown unknowns" or "out-of-the-blue" are the events which organization can not even imagine in the planning phase and there has no clue what they even might be. They might rise from unknown project environments or simply from the unanticipated interaction of previously known structural uncertainties (De Meyer et al. 2002).

Another way of categorizing project uncertainty is to evaluate elements that are under uncertainty. Huchzermeier (2001) recognizes the following five elements of variability:

1. Market payoff variability, referring to the uncertainty in received payments
2. Budget variability, referring to the uncertainty in cost evaluation
3. Performance variability, referring to the uncertainty in performance of project execution
4. Requirement variability, referring to the uncertainty of customer's requirements
5. Schedule variability, referring to the uncertainty in schedule

These elements of variability refer to the operational uncertainties in the project and describe the possible elements in the project that might be affected by uncertainty. While from the cost estimation point of view the variation of budget is the most interesting from these, are these elements nevertheless are linked; underperformance for example could cause schedule overruns and that in turn might cause budget overruns. Huchzermeier's list is not exhaustive, and other elements could be added as well, for example customer satisfaction or the benefits to the organization (Atkinson 1999) or performance against original design criteria (Hopfe & Hensen 2011).

3.2 Uncertainty as a cause for cost overrun

Uncertainty is often understood as the lack of information (Johansen et al. 2014). According to Saunders et al. (2015), there are five categories in the literature for causes of uncertainty:

1. Environmental uncertainties
2. Individual uncertainties
3. Complexity
4. Information uncertainty
5. Temporal uncertainty

Environmental uncertainties are caused by the project external factors, such as changes in project environment and project external factors. In contrast, individual factors refer to the different motivational, cognitive and psychological factors that create uncertainty to both the estimates and execution of the projects. Complexity of the project is often cited

reason for uncertainty, and for example Baccarini (1996) defines complexity as the product of differentiation and interdependence, differentiation referring to number of elements under variation and interdependence to the degree to which these elements are dependent on each other. Information factors refer to the uncertainty caused by the lack of information, either created from the impossibility to estimate causalities during the project execution or from the organizational estimation capabilities. Temporal factors are those sources of uncertainty that tend to change during the course of the project, for example uncertainty in certain time-critical phases of the projects.

Causes different authors have found for project overruns have striking similarities with the causes for uncertainty; it is sometimes difficult to distinguish the two from the literature. From this point of view the differences between the two seem often semantical. This is of course understandable; if there would not be any uncertainty associated with the project, there should also not be a possibility for cost overruns. If the cause for project overrun is not related to the project environment, it is often then related to the internal uncertainties created by organizational challenges. For example, both "lack of information" or "limited estimation ability" as a cause for project uncertainty from Saunders et al. (2015), can be linked either to the uncertainty in project environment or to the organizational inabilities that create uncertainty.

Shane et al (2009) divided the cost escalation causes into the project internal and external factors. Some overruns are due to internal factors of the project, like the inadequate cooperation between tender and contractors, and some due external factors, like changes in the country's legislation. Some causes for overruns can be a combination of both internal and external factors, for example when the organization fail to estimate external environment. Figure 3 below presents both causes for cost overruns and uncertainties analyzing whether they are internal or external causes; position in between means that it can be both.

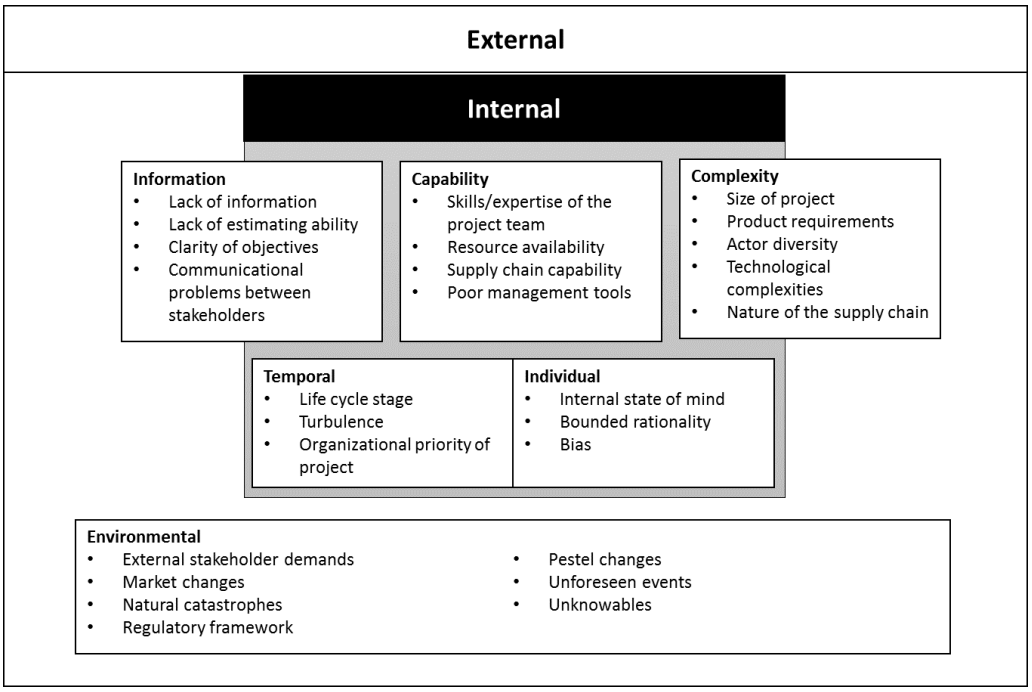


Figure 3. Fundamental project uncertainties and causes for project overruns (adapted after Saunders et al. 2015, Shane et al. 2009).

When looking at the list of internal factors causing uncertainty, it is easy to see how many of them are linked to different organizational and psychological factors either on the individual, organizational or stakeholder level. Even with the case of environmental uncertainties, many of the factors can also be seen from the point of view that the project organization was unable to analyze the environment of the project. This is the view De Meyer et al. (2002) adopt; it is not the uncertainties in the project characteristics or in the environment that cause project overruns, it is the failure to manage uncertainty that is the source of cost overruns.

Several studies which try to rank the causes for cost overruns have been conducted in the past. For example, Cheng (2014) cites the unclear scope definition, cost control and contractual matters as cost factors having most influence on cost overruns. On the contrary Le-Hoai, Dai Lee and Young Lee (2008) cite poor project management and project parties financial difficulties as the main reasons for project overruns. From the field of software development the insufficient and unrealistic project planning and project scope changes were among main causes for overruns (Van Genuchten 1991). Problem for these studies is that they are highly specific to the projects studied, and it is hard to generalize these findings for different types of projects or for different cultural regions. On the other hand, this demonstrates the fact that there is no simple single explanation for all the project cost overruns – projects by definition are unique and so are their overruns.

3.3 Uncertainty management literature

Uncertainty management literature can be linked to the seven schools of project management research recognized by Söderlund (2011). Söderlund (2011) categorized in his article the different views on project management and the base traditions of literature for which these schools of thought are based on. While Söderlund's review was generally about the project management literature, the same schools of thought can be used to categorize project uncertainty management literature. How the articles in this literature review are linked to Söderlund's schools of project management literature is presented in Table 4.

Table 4. Seven schools of project management and their link to uncertainty management (adapted from Söderlund 2011).

School	Examples articles from project uncertainty management perspective		Uncertainty management methods	Base traditions
Optimization school	Northcraft and Wolf (1984), Acebes et al. (2013)		Planning of the complex tasks, quantitative modelling methods	Management science
Factor school	Alter and Ginzberg (1978), Clark (1989), Atkinson (1999), Tatikonda and Rosenthal (2000)		Project success and failure determinants	Diverse
Contingency school	Pich et al. (2002), De Meyer et al. (2002), Sauser et al. (2009)		Project organization's design, contingencies, flexibility, coordination	Sociology, organizational theory
Behavior school	Engwall (2003), Grabher (2004)		Organizational processes, Learning, communication, creativity, culture,	Organizational behaviour, psychology

Governance school	Eccles (1981), Osipova and Eriksson (2012)		Governance of project organizations and stakeholders	Economics
Relationship school	Hellgren and Stjernberg (1995), Cova and Hoskins (1997), Vaaland, Håkansson (2003), Aaltonen et al. (2010)		Project network and stakeholder management	Industrial marketing
Decission school	Matta and Ashkenas (2003), Lovallo and Kahneman (2003), Cooper and Budd (2006), Williams and Samset (2010)		The interplay among decision makers	Political science

Firstly, optimization school is what is understood as traditionally management science: for example, gantt charts, budgets, scheduling and work breakdown structures. This school search for methods which help managers to optimize projects management with the help of mathematics and management science (Söderlund & Maylor 2012). In the field of uncertainty management this school can be recognized as the branch of literature aiming to optimize and model the uncertainty, and therefore deal with the uncertainty management by quantitative and deterministic methods (Saunders et al. 2015).

Optimization approach has been often criticized to be too deterministic by its nature (Acebes et al. 2014) and while they often include views on managing variability they often lack tools to manage unknowns. As a consequence, theories of optimization school often don't have clear picture about uncertainty management (Perminova et al. 2008). Authors in the optimization school have in the recent literature also themselves realized how their approach is limited by the amount of relevant and correct information and relatively stability of project environment (Jackson 2002, Söderlund 2011).

Secondly, factor school investigates the criteria for the project overruns and the characteristics for the uncertain projects. The logic behind this approach is that the successful recognition of these factors helps the project managers to design projects so that they have the antecedents of a successful project (Söderlund 2011). In the earlier literature the success was defined rather rigidly and was often limited to the traditional "iron triangle" (time, cost, quality) criteria for success (Ika 2009), but the recent literature has challenged

this view and taken other criteria for success into account as well (Atkinson 1999, Shenhar et al. 2001).

Thirdly, contingency school searches for ideal setups for project organization and draws from organizational theory (Söderlund 2011). This school often recognizes different characteristics of "project environment" that require different approaches from the organizational point of view. One classic example in the field of uncertainty management is the work of De Meyer et al. (2002) who suggest categorization of projects by their uncertainty and then adapting the management practices in the amount of recognized uncertainty.

Fourthly, behavior school is a diverse discipline on organizational behavior, which tries to solve uncertainty through the means of organizational processes such as communication, knowledge management or organizational learning. One example of this is the concept of organizational learning, by which the organizations can diminish the uncertainties of the future projects (Grabher 2004). The temporal nature of project organizations and the uniqueness of the project makes this organizational learning particularly problematic (Sydow et al. 2004).

Fifthly, governance school is focused on the administrating the project organizations and the stakeholder networks through control systems like contracts. Notable examples of developments in this field in recent years have been joint-risk management (Osipova & Eriksson 2013) and different types of alliances, that strive to divide the risks and rewards related to uncertainties so that the incentives strive stakeholders towards positive behaviors that support the project goal achievement (Love et al. 2010).

Sixthly, relationship school has strong marketing origin, and it has similarities with the both governance and relationship schools of project management (Söderlund 2011). This discipline also recognizes the importance of the early planning phase of the project and its importance on project management (Murtoaro & Kujala 2007), as well as the uncertainties caused by the interorganizational conflicts (Vaaland & Håkansson 2003). Relationship school underlines the dynamic nature of the projects and stakeholder relations and argue that adequate time and managerial resources should be directed towards the relationship management.

Finally, as the name suggests, decision school of project management is interested about different decisions that lead to the termination or continuation of the project (Söderlund 2011). For these decisions it is usually crucial to understand the impact of uncertainty to the project, and therefore sensitivity or uncertainty analyses are often made of before major decision points of the project (Leonard 2009). Improper understanding on uncertainty and bias can lead to the situation, where good projects are terminated, and the bad ones are being implemented (Matta & Ashkenas 2003).

These schools on uncertainty management literature can also be summarized into rougher two categories: authors who emphasize the element of planning, control and extensive risk management, and the authors who challenge this view and who emphasize uncertainty management and flexibility (Koppenjan et al. 2011). As Koppenjan et al. (2011) recognizes, both strands of literature are a bit disconnected, even though in the real life project managers must deal with the both aspects of project management simultaneously. Table 5 summarizes these competing viewpoints on uncertainty management.

Table 5. Comparing control and flexibility (Koppenjan et al. 2011).

	Control	Flexibility
Terms of reference	Blueprint	Functional
Task definition	Narrow	Broad
Contract	Task execution	Functional realization
Incentives	Work-task based	System-output based
Change	Limit as much as possible	Facilitate as much as needed
Steer	Hierarchical	Network
Information change	Limited, standardized	Open, Unstructured
Interface management	Project management task	Shared task

Flexibility is often used in a rather loose manner, referring to the capabilities to respond to change and as a response to uncertainty (Rahrami 1992). Flexibility is often used concept in project management that refers to the project managers desire to adjust projects as more information is gained about the project context (Olsson 2006). For example, in Olsson's (2006) study, flexibility was used always when it was a planned element in the project, and quite often also when it was not. Flexibility can be categorized in following six categories (Geraldi 2008, Osipova & Eriksson 2013):

- What: Ability to define and change the scope and goals of the project, for example contractual flexibility
- How: Ability to change how the project is implemented, for example the process or the instruments and tools used for project implementation
- Who: Ability to change who is carrying out the tasks in the project
- When: Ability to change when and in which order the tasks should be completed
- Where: Ability to define where the project tasks are undertaken
- How much: How rigid is the budget for the task, for example what is the budget responsibility for the actor responsible for the task

However, both control and flexibility are equally needed in order for organizations to avoid becoming too rigid and on the other hand to avoid organizations to slip into chaos (Volberda 1999). More concretely, according to De Meyer et al. (2002), the methods used to control the project should be selected according to the uncertainty profile project has. In the cases where a most of uncertainty is a result of variability and foreseeable

uncertainties, the emphasis should be more on controlling the uncertainty. On the contrary, when the emphasis is on unforeseeable uncertainties, the emphasis should be more towards flexibility and contingency planning. This is a similar conclusion to what Burns and Stalker (1961) arrive in their contingency theory: controlling management systems are sufficient for the stable projects and flexible systems for uncertain and changing projects.

3.4 Differentiating interpretations on uncertainty

Human psychology and differentiating interpretations on concepts are also on play when dealing with a complex and diverse concept such as uncertainty. This is true not only for participants of cost estimation process, but for the scholars as well: for most scholars, "risk" or "uncertainty" is not something that can be explicitly defined (Van Asselt 2000). Like Slovic (1987) puts this thought:

> "Human beings have invented the concept of "risk" to help them understand and cope with the dangers and uncertainties of life. Although these dangers are real, there is no such a thing as "real risk" or "objective risk"."

Thompson and Dean (1996) propose that the reason why people interpret risk differently is that people have fundamentally differentiating concepts of risk. Empirical studies demonstrate that this is true at least when comparing the concept of "risk" that the laymen and the experts have (Slovic 1987). Other example can be found from the human tendency to be more worried about unlikely events with dire consequences (for example airplane crash) than repeated events with smaller damages (for example, car accidents) (Van Asselt 2000).

Slovic et al. (2005) proposed that these concepts of risks people possess could be categorized as *risk as feelings* and *risk as analysis*. Risk as feelings "refers to individual's fast, instinctive and intuitive" reasoning, and risk as analysis "to logic, reason, and scientific deliberation". While the usage of intuition can be very effective for quick decisions, for uncertainty management these feelings can often result as less reliable in complex settings such as project management. (Slovic et al. 2005) Figure 4 applies this concept on to how the perception on uncertainty is formed.

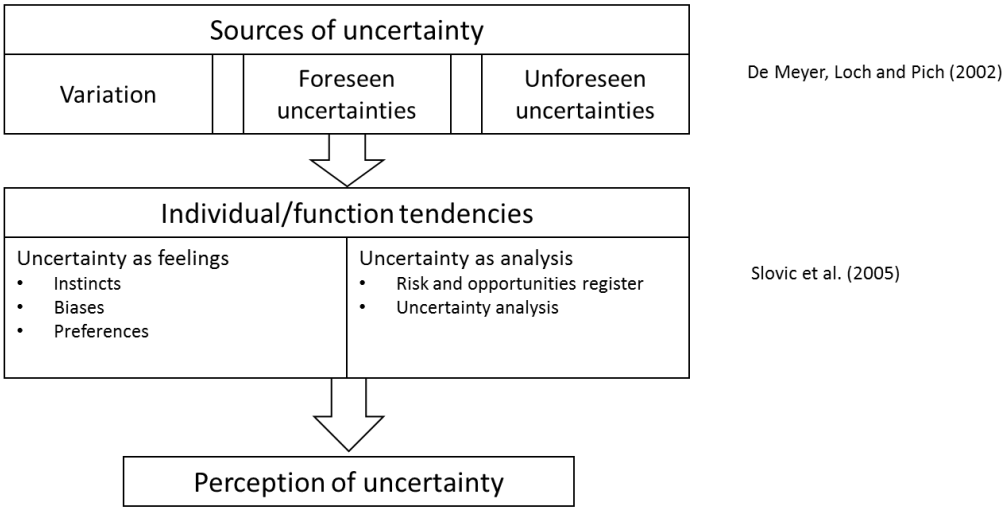


Figure 4. Perception of uncertainty (De Meyer et al. 2002, Slovic et al. 2005).

In project environments, there are de facto sources of uncertainty that can be categorized with the concepts of De Meyer et al. (2002). However, the interpretation and visibility of these uncertainties depends greatly on how the individual perceives uncertainty. Typically, both the analysis and the feelings are included into the decision making and these together form the individual's perception on uncertainty.

Classic way in the project management literature to analyze uncertainty is to assign a probability for it. However, even when the uncertainty is evaluated as probability, different interpretations on the concept can be easily spotted. For example, the Bayesian school on probability interprets probability to express the current state of knowledge, and Bayesian probability estimates are updated whenever new data emerges (Puza 2015). In contrast, classical frequentist school of probability treats probability in more deterministic way, i.e. believing that real-world phenomena have real, quantifiable frequency (Casella 2017). These two viewpoints on probability treat it fundamentally different way, other seeing it as measurable concept and other as subjective belief state. It becomes easy to understand why organizations or individuals can understood uncertainty differently when already the basic concepts allow multiple interpretations over the subject.

Different organizational functions take a very different look on cost estimation process. In a typical project setting sales function is more geared towards the initiating phase of the project, project function sees usually the implementation part and the business decision makers probably have the view over the whole project portfolio. This also introduces the own biases into the understanding of uncertainty as a concept. For example, salesmen are often seen to benefit from positivism (Rich 1999), and while this might have positive impact on sales, it might also include these positive biases into the cost estimation practices.

Regarding cost estimation, Flyvjberg (2009) categorized the biases involved into three categories: technical, psychological and political-economic biases. Technical biases occur due inadequate estimating techniques or from the estimator's mistakes. Psychological factors include psychological bias towards optimism and the way planners have tendency to overestimate the benefits and underestimate the costs. Finally, political-economical biases refer to the cases where actors involved in the cost estimation process have deliberate reasons to alter the results; for example in the political decision making when in order to get the project approval costs and uncertainties need to be understated. After the project has been approved, it is often difficult to cancel the project altogether even if the significant cost overruns are encountered. (Flyvbjerg 2009)

4. PROJECT COST ESTIMATION

4.1 Project, Project Management and Project life Cycle

Project is temporary undertaking which aims to create unique service, product or result (PMI 2008). It has a start and end date and involves a series of tasks and activities which consume resources (Munns & Bjeirmi 1996). Compared to this, the project management is the process of controlling the achievement of project objectives by allocating resources, scheduling, monitoring the progress and adjusting into changes from the initial project plan (Munns & Bjeirmi 1996).

Project management generally aims for project success, and literature recognizes many ways to define this. Most common criteria in the literature includes quality of the outcome, timeliness, budget compliance and a degree of customer satisfaction (PMI 2008). In the project management literature, cost, quality and schedule are often referred as the "iron triangle" due to their dominance in the literature in defining success, especially before 80's (Ika 2009). Atkinson (1999) criticized this traditional view to be too much focused on the performance of project process, rather than into actual results, and proposes to also take into account other possible benefits of the project, like for example benefits for the stakeholders and to the organization itself. While it is true that the iron triangle is very limited view to define success, in this thesis the focus is even narrower and project success is evaluated as terms of staying within initial budget. This is necessary in order to focus on project cost management – other success factors are interesting in this thesis only through the lenses of cost management.

Munns and Bjeirmi (1996) defined the six-stage model for the project: conception, planning, production, handover, utilization and closedown of the project. The initiating stage of conception and planning differs in the internal and external projects. In internal projects, this refers to the situation where the strategic need for the project has been recognized by the top management and the process of planning the methods to achieve this strategic goal (Pinto & Slevin 1988). In internal projects this can be as straightforward as Munns and Bjeirmi (1996) suggest in their model – organization recognizes the need and makes the plan to achieve this goal. In contrast, in the project where there is buyer and supplier, the conception and planning stages construct from complex negotiation phase between the buyer and the seller in which the contents of the project are determined (Murtoaro & Kujala 2007). This negotiation stage constitutes from both conception and planning phase of the project life cycle – typically during negotiations unrefined first plan for the project is created and this plan is then fine-tuned after the contract is signed. Williams and Samset (2010) refer to this early phase in the project as the project "front-end", which constitutes the activities from the initial idea of the project to the final decision to

execute the project. How the negotiation model of Murtoaro and Kujala (2007) and project life cycle model of Munns and Bjeirmi (1996) are linked is presented in Figure 5.

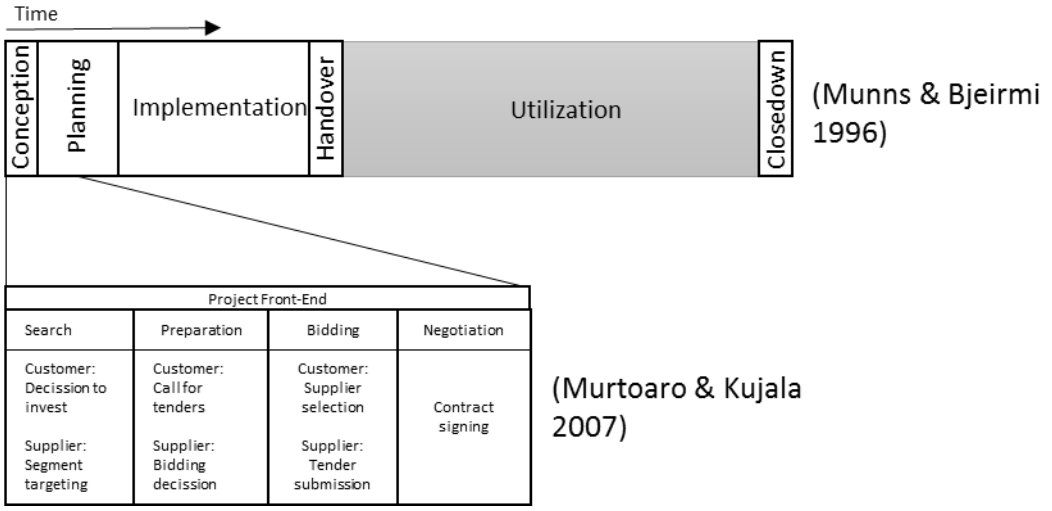


Figure 5. Project life cycle and the initiating phase (adapted from Murtoaro & Kujala 2007, Munns & Bjeirmi 1996).

Negotiations between buyer and supplier and the organizational limits create tensions and communicational challenges into the project and hence they increase the challenges for the project management. Like Munns and Bjeirmi (1996) note, typically project team is involved in the stages of planning, production and handover, whereas the customer is interested from the whole lifecycle of a project. Therefore also the success criteria for the project is different for the customer who is evaluating the whole project lifetime, and for the project management which is mainly evaluating the success and performance from planning to handover (Munns & Bjeirmi 1996). It is notable that these limitations can also be seen internally in supplier organization: sales function is only worried of the success of the negotiations, project team may see only the phases of planning, production and handover and finally the service organization is involved only in the utilization phase with the customer.

The stakeholder risk and uncertainty over the project as well as the influence are highest during the early phases of the project, and the "degree of freedom" decreases over time (Artto et al. 2001, PMI 2008). Most of the unanticipated surprises are often a direct consequence from the decisions made in the early stages of the project, which underlines the importance of these early planning and cooperation between project stakeholders.

4.2 Project cost management

Project cost management is the process of estimating, budgeting, and controlling costs in order to complete the project within the approved budget. Cost estimation refers to the process of developing approximation of the costs, based on the incomplete information or assumptions about the needed resources to complete the project. Budget determination

is a similar process, but also includes the resource gathering and typically official authorization of the project budget. Finally, the project cost control aims to keep the project under control in terms of cost by evaluating the project performance and doing necessary corrective activities. Figure 6 presents the typical overview on the process of project cost management. (PMI 2008)

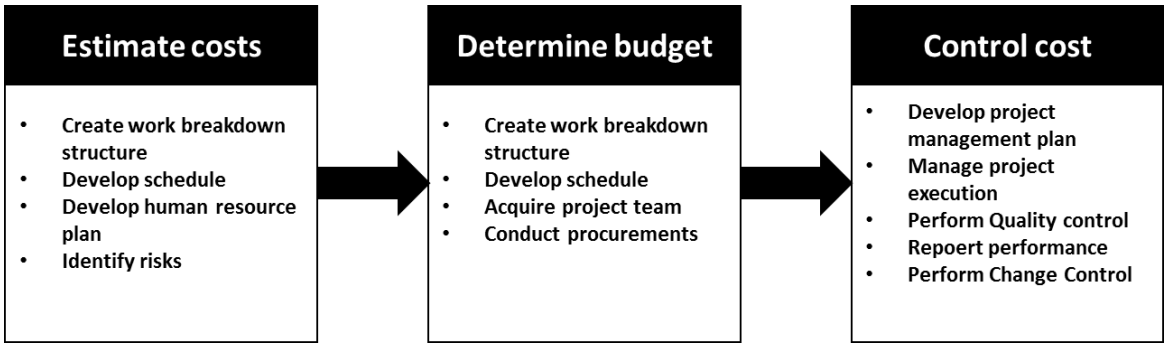


Figure 6. Project cost management process. Modelled after PMI (2008).

At first glance cost estimation and budget determination seem to overlap quite a bit, and in small projects they can be even performed by the same group of people. However, especially in the bigger organizations and projects it is typical that these activities are done somewhat separately, for example, first solely by sales organization and later as cooperation between sales and project implementation organizations. Furthermore, these phases differ from each other also in the terms of concreteness – in budget determination phase the resources needed for the project are usually ready to be committed for the execution of the project, while in the estimation phase they are not always even involved. For reasons in this thesis these phases are evaluated as separate entities in cost management process.

Whole approach of controlling project cost does not of course make much sense without reasonably good estimations about the project cost. In the case where the estimation is prepared for the tender in the sales phase the role of the estimation is especially important – overestimated price results probably to the lost tender, and underestimated or even unrealistic estimate will realize in the impossibility to meet the budget in the project implementation phase (Akintoye 2000). Even in the case that the project cost estimation is for internal purposes, the significance of good estimation cannot be neglected – the sensibility of the project cost control phase is only as good as is the original estimate.

4.3 Estimating project cost

PMI (2008) defines a cost estimate as a "quantitative assessment of the likely costs for resources required to complete activity". There are a number of reasons why project cost estimate is essential for project management. Firstly, it works as a tool to for which the project decisions are based on and is key tool in the negotiations and in the decision of project feasibility. Without some sort of cost estimate it is often impossible to conduct a

decision on whether to undertake the project or not. Secondly, it sets a benchmark for which the project cost control can be based on. Without cost baseline it would be impossible to track project costs during the project implementation. (Venkataraman & Pinto 2011)

PMI (2008) recognizes several inputs that typically are included in the process of cost estimation. These inputs to the process are illustrated in Figure 7.

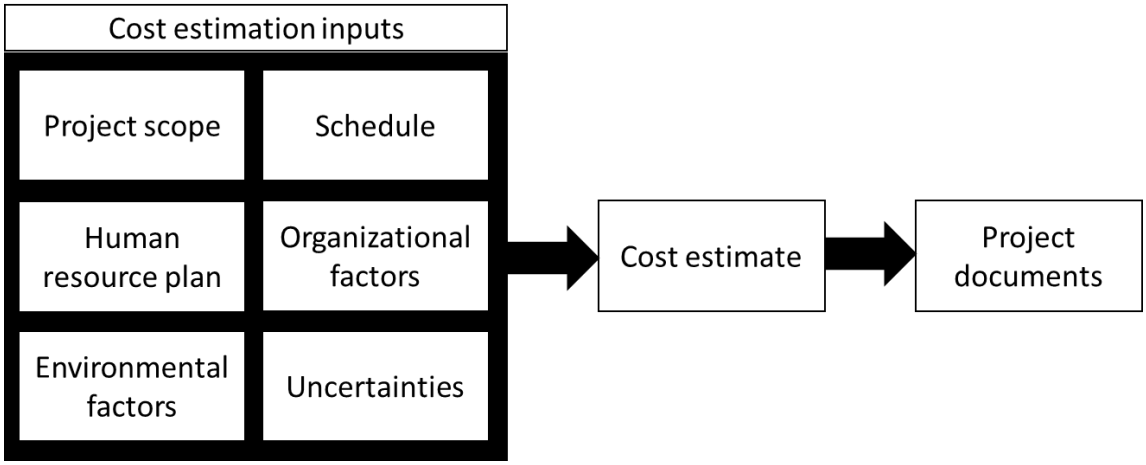


Figure 7. Cost estimation inputs (adapted after PMI 2008).

Project scope is the definition of the project, what it includes and what it does not (Cho & Gibson Jr 2001). It typically includes description of the project, key deliverables, project boundaries and assumptions about the project (PMI 2008). Important part of the documents and procedures defining project scope is often work breakdown structure (WBS), which is a hierarchical breakdown of the project into its elements (Khan 2006).

Project schedule is the description of the resource needs and their durations. This is usually closely linked to the human resource and project scope planning since the variation in duration usually also leads into variation in cost. Organizational factors are processes that affect the cost estimates, such as estimation policies, concrete templates and historical information about the project costs. Environmental factors are anything that affect the project cost estimates in the project environment, such as the cost of the necessary procurements. (PMI 2008)

Finally, uncertainties or risks are important input for the successful cost estimation. As stated in chapter 2.1., even though the literature often talks about risks as parts of cost estimate, in the scope of this thesis term “uncertainties” is preferred to include both negative and positive elements of risk for project cost estimates. Methods by which uncertainties typically are taken into account in the cost estimations often includes risk registers, risk mitigation costs and different types of contingencies (PMI 2008).

The knowledge over project is the lowest in the project front-end, and simultaneously that is also the time when decision-makers can have the most crucial impacts over project provided that they have the right information. At the same time, estimation phase is made by humans and affected by psychological, organizational and political factors which makes correct estimates and good decisions even harder (Williams & Samset 2010). However, as the studies of Williams and Samset (2010) and Scheibehenne and von Helversen (2009) commented, smaller amount of information where the less relevant information is omitted, can also help decision makers, provided that the information on which decisions are based on are selected carefully. Furthermore, in the front-end of the projects the quantitative estimates and assumptions tend to outdate fast, which creates further difficulties when trying to base decisions solely on the quantitative information (Williams & Samset 2010).

4.4 Cost control and uncertainty

After the project has started, the task of the project cost control is to track costs and help project manager to manage development of costs. Important concept in controlling the project costs is Earned Value Analysis, which compares actual work performed to date with the original budget (Fleming & Koppelman 2010). Based on this, the project manager can then evaluate how the project is doing compared to the original cost and schedule estimates and how significant the possible overruns are (Reichel 2006). Figure 8 presents an example of the Earned Value Analysis.

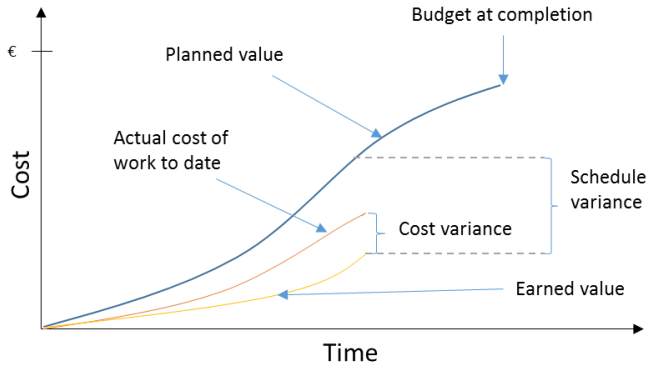


Figure 8. Earned Value Management.

Planned value is the time-based budget created in the cost estimation phase, which is the originally approved budget for project completion (Reichel 2006). Due its shape cumulative planned value curve is often referred as the S-curve (Anbari 2003). Tip of planned value curve represents the total project budget at completion (Anbari 2003), that is total planned cost at planned project completion date.

Other concepts of Earned Value Analysis refer to what has actually happened in the project. Actual cost of work to date, or project expenditures, are the cumulative costs that

have been spent to complete the project to date (Reichel 2006). In contrast, Earned Value represents the budgeted cost of accomplished work (Anbari 2003), and hence represents the actual value that was created with spent costs. Therefore, the difference between actual costs and earned value illustrates for project manager how much project is ahead or behind its budget, and finally difference between earned value and planned value represents the amount project is behind its budget.

Two indexes representing project performance can be varied from the above values. According to PMI (2008), Schedule Performance Index (SPI) equals to Earned Value (EV) divided by Planned Value (PV), so SPI = EV/PV. In similar manner, Cost Performance Index (CPI) equals to Earned Value (EV) divided by Actual Costs (AC), so CPI = EV/AC. One of the uses for these indexes can be to forecast the actual cost of the project at completion: simplest method for this is to divide the Budget at Completion (BAC) by current CPI (Reichel 2006).

Time-cost S-curves are also fundamentally linked to the uncertainty in the cost estimates. Planned values are estimated in the project front-end during the cost estimation (Reichel 2006), which means that it is uncertain whether or not they will represent the final project costs. Cost uncertainty analysis is a process of evaluating the project uncertainties and their potential impact on project cost (Garvey et al. 2016). Methods for coming up with the values may vary, but the results will often yield possible S-curves for the future project. Figure 9 represents these possible project budgets on cost-time axis.

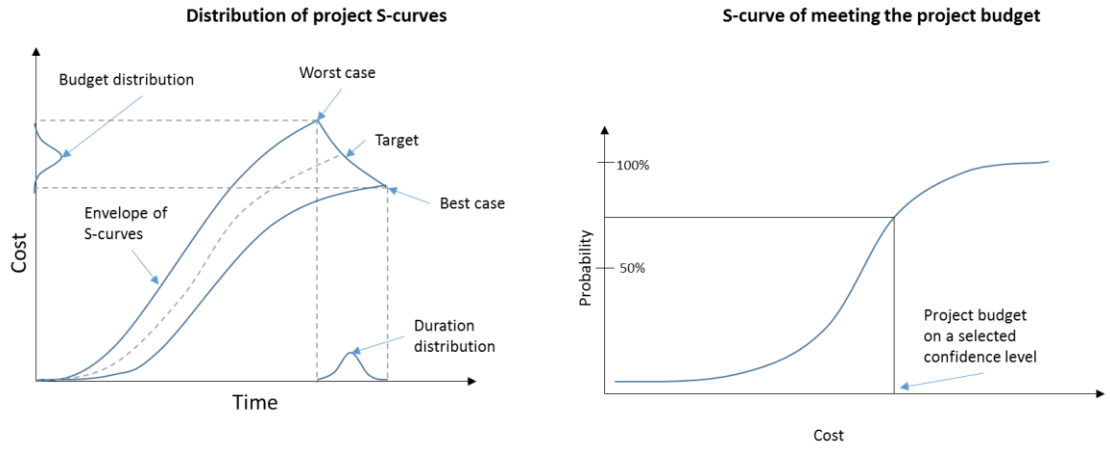


Figure 9. Link between S-curves and uncertainty.

As can be seen, these possible project S-curves fall typically between worst and the best scenarios, and are typically distributed around the most likely value (Barraza et al. 2000). These distributions can be translated into cumulative probability distribution, which is a typical outcome of the uncertainty analysis. Example of this can be seen on the right in Figure 9. These can be used in the project estimation phase to determine the desired probability for meeting the project budget, if the estimators know the amount of scenarios where the project costs are lower (Barraza et al. 2000).

Current project management theory emphasizes the front-end phase of the project for controlling project costs (Olsson 2006). Logic for this lies in the fact that the decisions in the conception and planning phase have much more impact on the project cost than the decisions later in the implementation phase (Venkataraman & Pinto 2011). Interestingly enough, also the potential for errors is the highest in the project front-end due to the high uncertainty associated with the early stages of projects. Opposite is true for the actual costs realized in the project and the cost of changes made in the project, as both increase over time. These are illustrated in Figure 10.

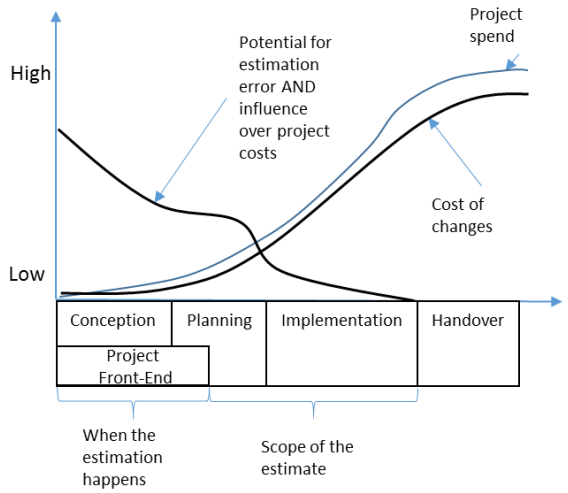


Figure 10. Potential for errors in estimates during project (adapted from Venkataraman & Pinto 2011, PMI 2008).

It is also noteworthy, that often at least some parts of the project lifecycle costs are omitted in the cost estimate (Chatzoglou & Macaulay 1996, Sterner 2000). For example, typically for the project cost control purposes the implementation costs are estimated. However, sometimes some part of the planning might happen only after the project has been scoped and sales-phase has ended, which can lead to poor project plans (Van Genuchten 1991). In practice this can mean that the project cost overruns are encountered immediately in the project planning phase if the original scope was based on poor estimation.

Project cost management process as a whole offers a good explanation why good estimation practices for projects are valuable for early decision making and why producing good estimates remains so hard. Good estimates are also important for the project cost control as an important input and baseline against which actual costs can be compared (Barraza et al. 2000). Uncertainty must be realistically evaluated also from the cost control perspective, so that the baseline against which project performance is compared is realistic.

4.5 Methods for uncertainty analysis

Many of the uncertainty analysis methods in use today have their root in the 50's, for example PERT method (see Malcolm et al. 1959). The reasoning behind performing project uncertainty analysis is to obtain understanding about the level of uncertainty associated with the project (Leonard 2009), and therefore one of its most important tasks is to evaluate and communicate the most critical risk elements to the decision-makers (Garvey et al. 2016). After the analysis appropriate mitigation or contingency plans can be implemented or, in most extreme cases, project can be completely cancelled.

Cost estimates are forecasts, so they include the element of uncertainty by default. Often in practice cost estimation process aims for single-point estimates and therefore lack completely the view on the uncertainties of the project (Leonard 2009). Garvey et al. (2016) define three levels of uncertainty related to the cost uncertainties: Cost estimation, system definition and requirements uncertainty. Firstly, cost estimation uncertainty refers to the uncertainty of costs associated with performing the individual tasks. Secondly, system definition uncertainty refers to the uncertainties in what inputs are actually needed to produce the desired result. Finally, requirements uncertainty refers to the possible ambiguity of the whole project definition and to the project results. These are illustrated in Figure 11.

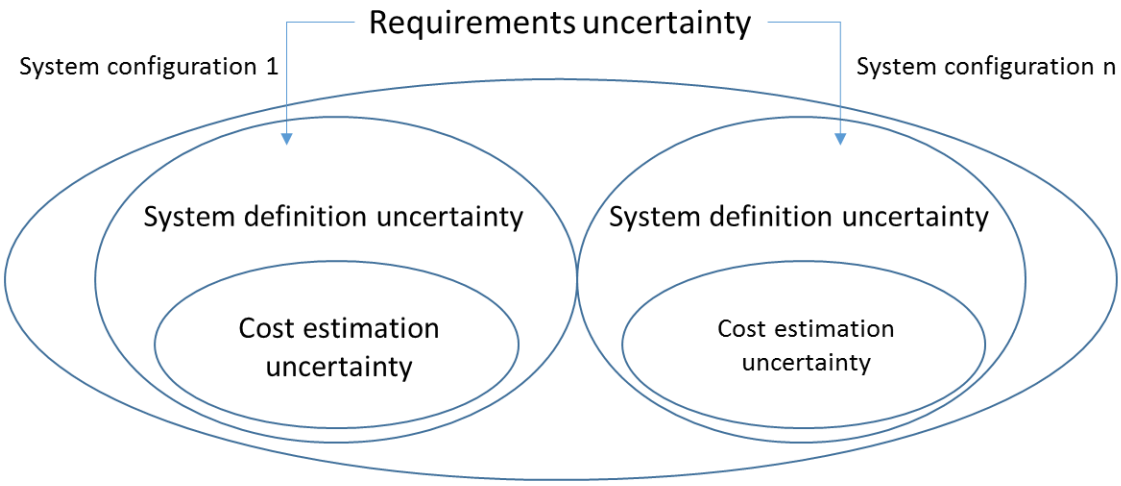


Figure 11. Cost uncertainty (Garvey et al. 2016).

Qualitative methods aim to describe the uncertainty in relation to project characteristics, such as complexity, technical details or contractual issues. Quantitative ways of estimating project uncertainty aim to evaluate the uncertainty associated with the project mathematically by using appropriate probability distributions for meaningful project components (Garvey et al. 2016). Qualitative and quantitative methods for uncertainty analysis are not exclusive, for example Chapman and Ward (2003) argue for the use of both methodologies. According to the authors, "the effectiveness and efficiency of quantitative analysis is driven to an important extent by the quality of the qualitative analysis and the

joint interpretation of both" (Chapman & Ward 2003). The quantitative analysis can give meaningful information only when the characteristics of the project are properly understood and analyzed.

Shash and Al-Khali (1992) conclude in their study that contractor's previous experience with the project type is the single most correlating factor with the accurate cost estimates. In similar manner, Akintoye and Fitzerald (2000) found out the main issue with the cost estimation inaccuracy to be the lack of substance knowledge of the cost estimators, insufficient documentation and insufficient time for cost estimate preparation. These are all factors that typical uncertainty analysis does not take into account, and which consequently increase the inaccuracy of both cost estimate and the analysis on project uncertainty. Whether the uncertainty analysis is performed with qualitative or quantitative methods, the key question with it is its reliability and accuracy.

4.5.1 Qualitative methods for cost uncertainty analysis

Traditional way of performing qualitative analysis is to gather a risk and opportunities map, and then accompany these with perceived probabilities and cost impacts for each identified risk and opportunity. Further characteristics may be included as well, such as urgency of the uncertainty or a categorization of uncertainties by their source or the area of the project that the uncertainty might affect. These risks can be gathered either from the past experiences, from the database of past realized risks or from the expert judgement of the project stakeholders. (PMI 2008)

Mitchell et al. (1989) recognized how prospective hindsight, i.e. generating explanations for future elements as if they have already happened improved the decision-makers ability to form plausible explanations and root causes for future events. Klein (2007) applied the idea for project as "project pre-mortem". Like the name suggests, instead of analyzing in retrospect why project failed, the method is to do this analysis before project start. This requires gathering all relevant project stakeholders and the project team into the same session and asking them to imagine every possible reason why the project failed. Often in the typical risk mapping session participants are trying to think what might go wrong, but in the project pre-mortem the assumption is that the project has already failed. According to Klein, this often helps to surface potential uncertainties and concerns that are often not mentioned and remain therefore unknown for project decision-makers. Klein's method is focused on the risk aspect of the uncertainties, and one could ask if the pre-mortem analysis could be extended to the opportunities as well by imagining every possible reason why the project was a success.

Project uncertainty can also be evaluated through project characteristics, such as complexity. Good example of this is the novelty, technology, complexity and pace diamond of Shenhar and Dvir (2007), where the projects are analyzed against these four criteria to draw some conclusions about the potential uncertainties and the lack of organizational

capabilities associated with the project. In similar manner, 6 W's framework of Chapman and Ward (2003) allows the potential uncertainties of the project to be mapped in the meaningful way. Both models rely on identifying the "usual suspects" of uncertainty and then adapting project management to correspond with the perceived uncertainty.

4.5.2 Quantitative methods for cost uncertainty analysis

Literature proposes many ways to define uncertainty quantitatively. Historical data acts as a common starting point for producing uncertainty estimates, the reasoning being that certain types of projects will encounter similar project cost overruns in the future as they did in the past. Often more sound way of estimating is parametric estimation, which means the identification of typical factors for the project that cause uncertainty. In the project context these can include for example such factors as project location, project type and project size (see for example Hegazy & Ayed 1998). It is also typical to accompany mathematical modelling into these estimates, for example regression (Trost & Oberlender 2003) or neural networks (Kim et al. 2004).

If the uncertainty is not analyzed based on project's general characteristic, the other common way of performing uncertainty analysis is to perform some form of probability or sensitivity analysis either for the project cost components (Leonard 2009, Mohamed & McCowan 2001) or for the different project scenarios (PMI 2008). One of the simplest examples of this is the usage of three point estimates, in which the worst case, most likely and the best case values are defined to the project cost components, or the simple sensitivity analysis, in which one project cost element is changed at the time and the impact on project costs are observed (PMI 2008).

One of the most common methods for extending three point estimates is the Monte Carlo method, which was developed in the 1940 and it was first used to estimate the behaviors of neutron chain reactions, and it has since then spread to the wide range of different problems and disciplines (Eckhardt 1987). Monte Carlo is essentially a statistical sampling technique, and the basic idea is to evaluate the probability distribution of the output variable by sampling the input variables repeatedly. In the context of analyzing risk and uncertainties associated with the business decisions the method was first proposed by Hertz (1964) who applied the method to capital investment decisions. Since then the popularity of the method has increased significantly, especially with the advances of information technology and the general availability of the modelling and computational capabilities that Monte Carlo simulation requires.

In the field of project cost estimation, the process of Monte Carlo simulation goes roughly as follows (adapted from Greenland 2001, Chau 1995, Sadeghi et al. 2010):

1. Divide the project into meaningful cost elements

2. Estimate the probability distributions of these elements, either from historical data or from expert judgement
3. Determine the correlations between cost elements
4. Simulate the project adequate amount of times (typically hundreds or thousands repetitions to produce the probability distribution for the total project cost

Popularity of the Monte Carlo estimation can be explained by the fact that it is fairly simple to execute with the help of modern information technology and it can be scaled in the many different types of problems (Kroese et al. 2014). Furthermore, Monte Carlo offers insights into the randomness and therefore to the uncertainty: when properly done Monte Carlo can produce good insights into the potential variation, sensitivity and probability associated with the business problem (Hertz 1964).

Downside of Monte Carlo method is, like with any mathematical model, that it is only as good as the data put into the model. Monte Carlo method can only take into account those parameters that are fed into the model, and therefore it can not prepare the organization for "unknown unknowns" (Baccarini 2005, Baccarini 2006, PMI 2008). Furthermore, success of Monte Carlo method requires that the probability distributions used with it are objective and realistic enough for realistic outcomes. When the uncertainty of the project increases, it becomes harder to produce good probability distributions.

Producing probability distributions is not a problem when there is adequate amount of historical data available from past experiences, but unfortunately this is not always the case. Often uncertainty analyses are performed on the projects that are new to the performing organization or, alternatively, prior data from past projects is not valid or available from some reason. In this situation it is possible to base possibility distributions to the expert judgement, but this creates a conflict between simplicity and objectivity of the Monte Carlo simulation; often practioners make heavy simplifications and assumptions (Chau 1995). This creates a risk of drawing conclusions from the data that relies on the biased underlying assumptions (Sadeghi et al. 2010). If the expert opinion is biased, the outcome of the Monte Carlo simulation will be biased as well.

Even though the rough process of performing Monte Carlo simulation remain the same, there is a wide variety of different extensions to the base methodology. Among suggested are the use of fuzzy sets (Sadeghi et al. 2010), extension of Monte Carlo with game theory (Madani & Lund 2011) or the integration of Monte Carlo methodologies to the cost control process (Acebes et al. 2014). Despite the advanced methodologies that exist in literature, it is good to note that in practice often very simplified version of Monte Carlo method is applied, and for example the independency of cost components and use of triangular distributions are typical assumptions (Chau 1995, PMI 2008).

4.6 Contingency

Outcome of quantitative uncertainty analysis is often cumulative probability distribution, or the S-curve, which then correlates the predicted project cost with their respective probabilities (PMI 2008). This kind of approach allows decision-makers to adjust the project budgets to the desired risk they wish to take with project cost overruns, and allows managers to understand the variation associated with the cost estimates (Hertz 1964). If the results of the uncertainty analysis are presented at time-cost chart, contingency can be understood as a difference between desired probability of reaching the project budget and most likely scenario. This is illustrated in Figure 12.

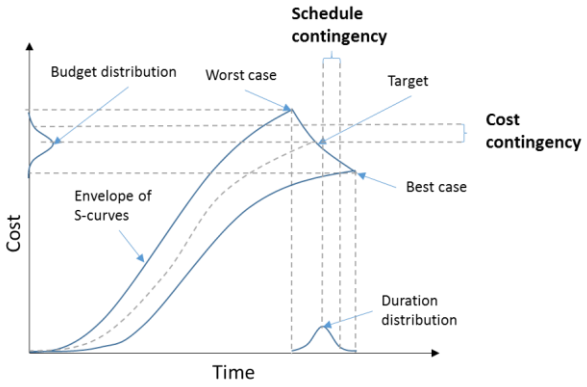


Figure 12. Contingency and uncertainty analysis.

However, results of qualitative uncertainty analysis are not this easy to link into the contingency. Often the results of qualitative uncertainty analysis is a register of risk/opportunity events (PMI 2008), which can affect the cost. However, lot of uncertainties usually still remain, for example of what is the probability of that risk event or when it could happen. If all these facts were known, typical risk event like this could be illustrated as in Figure 13.

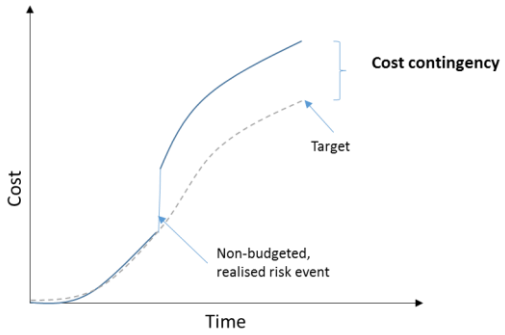


Figure 13. Contingency and risk event.

Unfortunately, the amount of risks and opportunities recognized in a typical qualitative uncertainty workshop can be very high, and their probability is not usually reliably defined (PMI 2008). This is also definition of qualitative uncertainty analysis – if the exact

probabilities of uncertainties would be known it would be qualitative uncertainty analysis. Therefore, contingency can not be claimed to represent any mathematical relation to all the risks; rather in these cases contingency that is defined qualitatively represents agreement or educated guess about cost contingencies that is required to cover for unanticipated foreseen or unforeseen uncertainties.

Traditionally contingency is understood as a buffer that is allowed for project costs that protects against cost uncertainty (PMI 2008), and its use is typical in the industries where the cost overruns are more of a norm than anomaly (Baccarini 2005). Despite the wide adaption of cost contingency concept, it is also very loosely understood among project management practioners, and therefore its applications vary (Baccarini 2005, Patrascu 1988). Baccarini (2006) defines following four tasks for contingency:

1. Contingency acts as a buffer for project costs
2. Contingency represents the total financial commitment of the project organization to the project
3. Contingency communicates uncertainties of the projects
4. Contingency affects to the behavior of the project stakeholders

Firstly, cost contingency as a buffer of money is how the contingency is generally understood among project management practioners (Baccarini 2006, PMI 2008, Baccarini 2005). This view is so common that there is a risk that contingency is understood only as a buffer. This easily leads to the conclusion that contingency is something extra that project management should get rid of or that project should be accomplished without it. For example, Baccarini (2005) found out that the project cost estimators rarely in practice manage to link risk and contingency as concepts to each other, even though the two clearly are linked.

Secondly, contingency with the base costs estimate represents the amount of money that is committed to the execution of the project (Baccarini 2006). However, this is not always the case: for example, if the contingency is calculated for the sales cost estimation purposes by the supplier, it is often the case that the supplier has the obligation to deliver the project with agreed price despite of cost overruns. Furthermore, as Flyvbjerg (2009) notes, in the large projects it is often difficult to stop the project in the case of the project cost overruns start to occur. Nevertheless, contingency helps project stakeholders to form overall picture what is the expectation of costs and financial commitment (Baccarini 2006).

Thirdly, contingency is also a tool to manage uncertainties in the project. Amount of contingency should be proportional to the level of project uncertainty (Venkataraman & Pinto 2011), and should therefore also act as a tool with which decision makers can be informed about the uncertainty of the estimate. However, it is not uncommon to find practice where the amount of contingency is completely based on intuition and therefore very hard to

justify (Yeo 1990, Idrus et al. 2011, Baccarini 2006). This kind of fixed percentage or amount gives no information to the different stakeholders about the real uncertainties associated with the project, and in the worst case it communicates the false certainty associated with the project cost estimate (Baccarini 2006).

Finally, contingencies have implications on the behavior of project stakeholders: unreasonable high contingencies can cause poor cost management and inefficiencies in the project implementation phase, while low contingencies can result to cost overruns and tensions between project stakeholders (Baccarini 2005). Finding optimal balance for the contingency and ensuring that it corresponds with the reality is therefore crucial for it to support project management and decision making.

This study approaches contingency as a tool to communicate the uncertainty. Contingency as a concept should match the uncertainties presented by De Meyer et al. (2002), and it is calculated on top of the base cost estimate which sums the expected costs for project items. Even though contingency is not bound to any specific cost item, it should be not thought as an "extra"; it should be seen as a part of the resources needed for project completion (Querns 1989). This is illustrated in Figure 14.

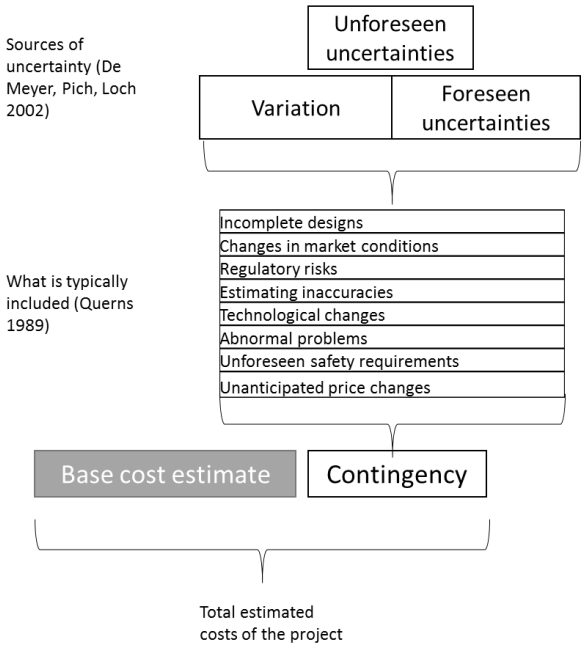


Figure 14. Contingency as a quantification of uncertainty.

As can be seen in Figure 14, not all unforeseen uncertainties should be included in the contingency. For example Moselhi (1997) and Querns (1989) argue that the scope changes should not be involved in the contingency estimate. This is further supported by the views of project management practioners (Baccarini 2005). Simple reasoning for this is the fact that scope changes can change the nature or for example the size of the project significantly; it is unrealistic that the contingency should cover for example situations, where the content of the project doubles.

5. CREATING COMMON UNDERSTANDING ON UNCERTAINTY

5.1 Organizational interfaces for cost estimation

Often in the process of project cost estimating, there are multiple organizational functions involved in the process. For example, in construction projects large group of people consisting of directors, project team, professional estimators, sales and procurement are usually involved, and it is not unlikely that the cost estimation is completely separate organizational function itself (Akintoye & Fitzgerald 2000). In similar manner in other industries, many internal and external stakeholder groups are involved in the process; for example, in the software-intensive projects cost estimation practices typically involve a wide range of experts from managers to programmers (Hihn & Habib-agahi 1991).

In most project organizations sales and project organizations are separate units (Cooper & Budd 2007), and the study of these two interfaces has highlighted some typical issues in the organizational interface management. Sales function acts as the mediator of information between the customer and the project function, and is often responsible for negotiating and formulating the contract with the customer (Turkulainen et al. 2013). Most notably, as a part of this process the sales function is often responsible of forming the quotation and therefore of estimating the cost for the project. However, the best knowledge about different cost factors of the project is usually situated in the project function. Therefore, one of the main challenges between sales and project functions is the gathering of right information and communicating this information between the functions in timely manner (Terwiesch et al. 2002). This makes integration between sales and project functions crucial to ensure successful projects (Turkulainen et al. 2013), and in the context of this thesis in ensuring the right estimation of the project costs. Figure 15 illustrates the differences between these two organizational functions.

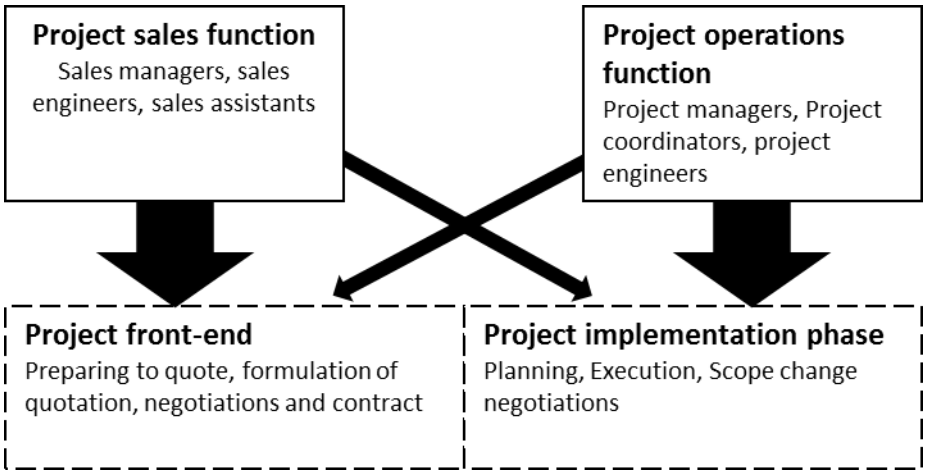


Figure 15. Integration of sales and project functions (Turkulainen et al. 2013).

The sales-project interface is not the only organizational interface from which similar issues can be recognized and which affect the cost estimation practice as well. For example, Thamhain (2013) recognized that senior management is often not perceiving a strong link between risks and project performance. This kind of failure from the managerial side to understand the linkage between estimate result and the components which it is based on might introduce serious biases to the estimate or the interpretation of the estimate.

It is therefore understandable that interdepartmental cognitive differences and interdependence in project execution are a significant factor creating uncertainty and biases to the cost estimates (Adler 1995). In order for the project organization to process information as a system despite the complex organizational structure, both amount of information and the richness of information conveyed between the functions must be ensured; richness referring to the fact that often purely numerical or technical information is not enough to solve communicational problems (Daft & Lengel 1983). Face-to-face meeting between functions is an example of a rich information channel through which different organizational functions can communicate and increase common understanding. It is critical for successful cost estimates to take a look into the interaction processes between organizational functions and between vendors and clients to ensure that the current estimation assumptions fit together with the project context and realities (Gopal & Gosain 2010).

5.2 Knowledge boundaries and boundary objects

Organizational theory acknowledges the existence of organizational boundaries, for example, between the organization and its external environment, between individuals and between different organizational functions (Aldrich & Herker 1977). In this thesis the main interest are boundaries between different organizational functions. Transferring knowledge and information across these organizational boundaries can be rather difficult (Bechky 2003) because individuals interpret their organizational surroundings from their

occupational position and tasks (Van Maanen & Barley 1982). Different organizational functions develop their own unique work cultures, language and gather their own unique knowledge (Bechky 2003).

Norreklit et al. (2006) defined these sets of "accepted perspectives, concepts and arguments" as "topoi". Subjective topoi refers to the reality different actors have, which originates from the fact that there simply is too much information to be analyzed thoroughly for any individual or organization; therefore different actors develop their own sets of concepts through which they interpret reality. When these actors communicate, cooperate and interact, they construct shared, organizational topoi. These shared patterns of communication and analysis, organizational topoi, can then be used to enable communication between different actors and to support decision making.

Carlile (2002) defines three different views of knowledge boundaries that can exist between individuals and groups:

1. Syntactic
2. Semantic
3. Pragmatic

Firstly, syntactic boundaries refer to those that can be grossed with the help of common syntax, which is precisely and explicitly defined, such as math, programming code, language or rules of accounting. Idea is that once different functions share a common syntax, it can be used to communicate across the organizational boundary. Many accounting and control practices fit well into syntactic definition of knowledge, and problem often arises with unexpected situations when the current syntax is not sufficient to process and transfer the information. (Carlile 2002)

Secondly, semantic boundaries are based on the notion that expression of knowledge, such as word "uncertainty" can have multiple meanings attached to it (Barthes 1977). Therefore, even if the boundary shares a common syntax, different functions can have different interpretations about it (Carlile 2002). Different concepts can have different meanings for different people, depending on their earlier experiences and background and current mental state; to put it short, human beings interpret their surroundings (Denzin 1983). Communication across semantic boundary can sometimes be helped by forming "mutual understanding and making tacit knowledge more explicit" (Nonaka 1994).

Finally, pragmatic knowledge boundaries also take into the account motivational and political aspects of boundaries by examining the consequences of the knowledge transfer. For example, when different functions have different organizational interests they might be reluctant to share the information they have. Approach takes into account that different parties participating in the knowledge sharing might have negative consequences on doing so or at least have a feeling that knowledge sharing harms them. Therefore, the motivation and incentives needs to be facilitated as well when working across knowledge

boundary, so that different actors are willing to share the knowledge they have. (Carlile 2002)

Interestingly, Flyvbjerg's (2009) three accounting biases technical, psychological, and political-economical, seem to match perfectly to the knowledge boundaries categorization of Carlile (2002). This gives a good practical example on how these boundaries are in effect in practice in communication. When communicating accounting facts, mistake in syntax usually leads to technical errors. When semantic factors are in play and the communicating parties interpret reality differently this leads to different psychological biases. Finally, if the parties deliberately misinterpret or distort accounting information, it is an example of practical knowledge boundary and leads to political-economical accounting errors.

Hinds and Pfeffer (2003) took a different approach to especially cognitive and motivational barriers in play when expert occupational workgroups share knowledge and these barriers of Hinds and Pfeffer are good examples of semantic and practical boundaries. These factors can be categorized in the following categories (Hinds & Pfeffer 2003):

1. Expertise gap
2. Tacit knowledge
3. Disincentives and the lack of incentives

Firstly, expertise gap refers to the phenomena of experts conceptualizing information they have that allows them to process information more rapidly, but which at the same time causes them to be unable to communicate this to the people not as familiar with the subject (Hinds & Pfeffer 2003). Naturally also the level of complexity of the information increases with expertise, making information and the concepts that the experts have too difficult for people new to the field to understand.

Secondly, tacit knowledge in contrast refers to the knowledge of the experts learnt through experience and that they are altogether unable to articulate or are even unaware of knowledge's existence (Leonard & Sensiper 2011). Expertise gap and tacit knowledge as concepts are similar to "topoi" of Norreklit's et al. (2006) in that they are based on human tendency to create models, simplifications and interpretations to make sense of reality.

Finally, disincentives or the lack of incentives refer to organizational barriers that demotivate individuals from transferring the information, for example due to fear that the information will be used against them (Orlikowski 1992). Incentives are therefore one important example of Carlile's (2002) pragmatic knowledge boundary.

Concept of "boundary object" is a concept that can be used to facilitate and explain ways to overcome these knowledge boundaries. In sociology, "boundary object" is an artefact, physical or abstract, that has different meanings or usages for the different social groups;

boundary objects "inhabit several intersecting social worlds and satisfy the information requirements of each of them" (Star & Griesemer 1989). Adopted in the field of management, this means physical object or abstract concept used to convey information between different organizational groups and across knowledge boundaries, such as budgets, timelines, or enterprise management systems. Boundary objects can help the different occupational communities to find "a common ground" and thus enable knowledge sharing (Bechky 2003). In business organizations boundary objects concept can be applied by accepting the fact that multiple meanings exist in different organizational functions, and then enabling and encouraging interaction with the help of boundary objects (Bechky 2003).

In addition to boundary object, in his study Carlile (2002) also adopts the concept of "ends", which represents all those outcomes that different individuals or organizations aim for – such as signed sales deal, implemented project that met its budget or meeting target profitability. This might also include personal ends, such as higher salary, promotion or avoidance of unpleasant tasks. To put it short, "ends" represents different motives that are affecting interaction and decision-making.

Different actors communicating across knowledge boundaries can be analyzed through the lens of Carlile's (2002) objects and ends framework. Ends help to shed the light to the different goals, incentives and motivations different actors have, and objects help to define what kind of concrete tools participants use that are related to their practice. Shared objects between practices, which convey different meanings for participants can be viewed as boundary objects. It is important to notice the difference in this framework between the objects and boundary objects: objects are something that only specific function is using in their internal culture that is essential for their profession; however, they are not used to communicate these concepts to the other functions. In contrast, boundary object is used by both functions and therefore it creates common ground and understanding over project uncertainty. Figure 16 presents the example of this typology and different groups related to the project cost estimation practice.

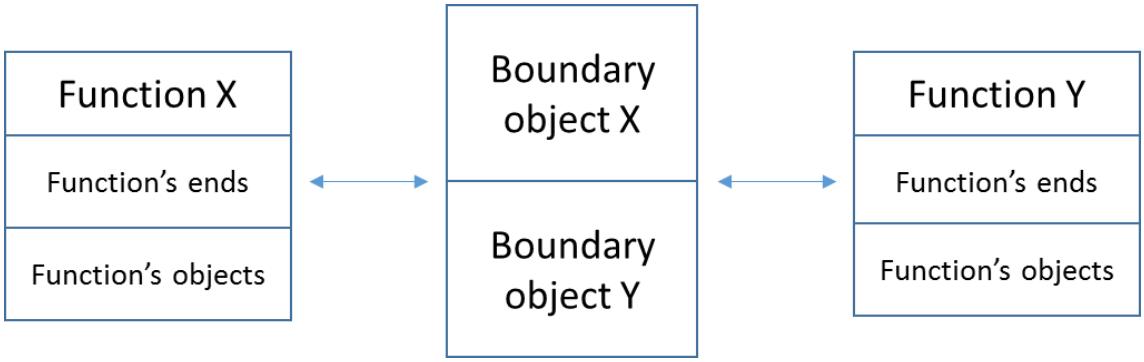


Figure 16. Object's and ends framework.

In her study Bechky (2003) noted how workers disliked using official CAD drawings as a boundary object and preferred simple prototypes over them. This corresponds well with

Levina and Vaast (2005) concepts of designated boundary objects and boundary-objects-in-use; designated boundary objects are those artefacts that are consciously designed to be boundary objects, and boundary-objects-in-use are those that the communities actually use when transferring knowledge. This categorization demonstrates how boundary objects are not always a result of careful planning and control practices of management; instead, they can sometimes be spontaneous ways through which different organizational functions learn to use for communication.

Spee and Jarzabkowski (2009) studied how boundary objects concept can help to understand the actual usages of strategy tools in organizations. According to Spee and Jarzabkowski's (2009), strategy tools are not always applied according to the procedure, their usage is shaped by the context in which they are created and their results are subject to interpretation in different organizational settings and functions. This is likely to be true also for other abstract concepts like uncertainty and uncertainty analysis, and therefore it is possible to use the concept of boundary objects to gain insights into why uncertainty is understood so differently across different organizational functions. More generally, same applies to cost estimates which are not based on the historical data but the expert estimate: Experts are also including their own biases, views and goals in the estimates.

5.3 Communicating uncertainty through uncertainty analysis

Uncertainty analysis, and its result contingency, can also be understood as boundary object through which different organizational groups, such as sales, project team and management communicate the uncertainties they associate with the project. These groups are also likely to adapt differentiating views over this analysis and use the uncertainty analysis for different purposes. For example, project manager might be interested about the most uncertain elements of the project, so they can be properly managed, whereas management might be more interested to know if the uncertainty associated with the cost is at the acceptable level.

In this thesis the framework of boundary object is combined with the taxonomy of Slovic et al. (2005) presented in Section 3.4., *uncertainty as analysis* and *uncertainty as feelings.* Furthermore, boundary object is understood as uncertainty as analysis, through which different types of uncertainty recognized by De Meyer et al. (2002) can be analyzed in the project environment. Different organizational functions have different views on the sources of uncertainty that exists and is associated with the project. Different functions use their objects and ends, or analyses and feelings to map out the uncertainty of the projects and through those form their own perception on uncertainty.

Uncertainty analysis as a boundary object steps into the picture when these functions then interact and communicate their perspectives on uncertainty across knowledge boundaries and hence form organization's shared perspective on uncertainty. Uncertainty analysis

acts as a boundary object, through which different functions communicate their perceptions about the project uncertainty that they have grasped from the project environment. This analysis creates the shared perception on uncertainty, which in turn will affect different functions own perception on uncertainty. This influence can be seen for example if the functions change their attitudes and feelings towards project uncertainties or if they adopt or change tools to analyze uncertainty.

Furthermore, as discussed in Sections 4.4. and 4.6, the two types of uncertainty from De Meyer's et al. (2002) categorization that can be analyzed from the project environment are variation and foreseen uncertainty. That is because unforeseen uncertainty events are by definition something that can not be analyzed thoroughly, and therefore organization's visibility to these remains limited. Starting point for the framework is therefore that there are two types of uncertainty analyses that can be constructed from the project environment: analysis on variation of the cost items and analysis of foreseeable uncertainties. These both act as boundary objects. This framework is illustrated in Figure 17.

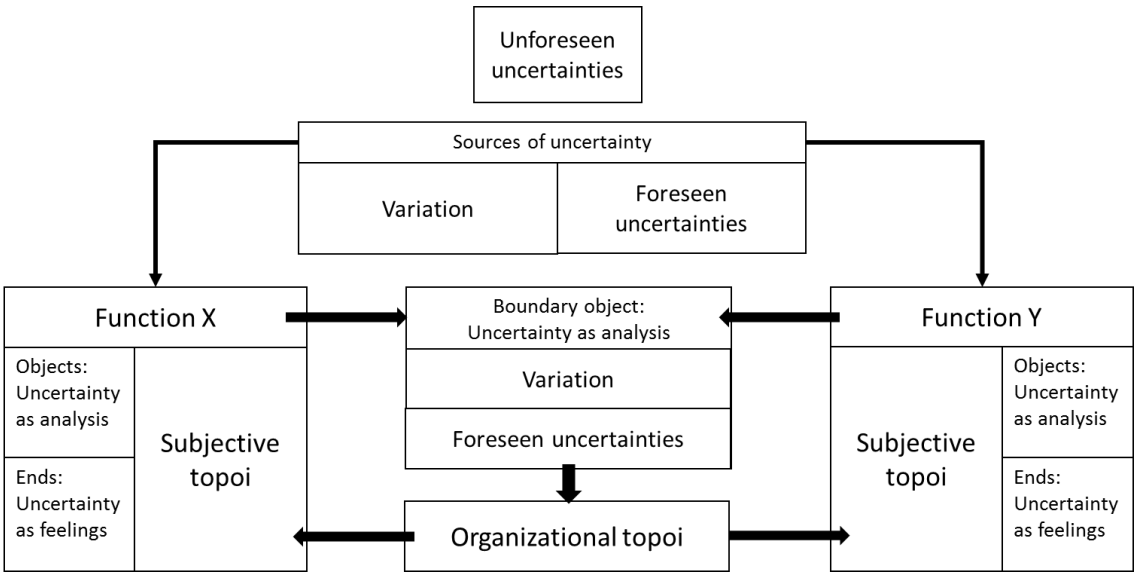


Figure 17. Uncertainty as boundary object.

Without translating the perception of uncertainty through boundary object like uncertainty analysis, different functions may try to communicate their perceptions through other means that might not be designed for the purpose. While these kind of boundary objects-in-use might be useful and work in some certainties, there is a risk that uncertainty is not really managed and that different functions continue to hold completely different views on uncertainty.

Concept of boundary objects has been popular tool for many practice-oriented studies, to the extent that the original definition has often been stretched too far from the original concept (Lee 2007). And rightfully so, because if every meeting, process or table in the organization becomes boundary objects the theory loses its explanatory ability (Nicolini

et al. 2012). Every concept is not boundary object; boundary objects are meaningfully used in practice in different organizational functions and incorporated in their work (Star & Griesemer 1989). However, in the context of this thesis boundary object is useful concept to understand and label the artefacts through which the uncertainty is communicated across organizational boundaries. Concept of boundary object forms a good framework for the purpose of this thesis through which the differentiating meanings and communication of the uncertainty can be evaluated. However, it is important to limit the usage of boundary objects into the objects that are related to uncertainty and not to fetch the scope of this thesis too far.

6. CASE COMPANY

6.1 Information gathering about the case company

This chapter presents overall information about the case company and its current cost estimation practices, and it is based into various interviews with different functions which were executed at the beginning of the thesis project. These interviews and extensive discussions are presented in Table 6.

Table 6. Interviews and extensive discussions.

Position	Number of interviewees	What was the information gathering purpose
Regional manager	2	Overall process of the project deliveries, Current practises, best practises, examples of cost overruns
Head of Project and Customer Services	1	Overall process of the project deliveries, Current practises, best practises, examples of cost overruns
Sales Manager	5	Tools and analysis used by the sales function, overall sales process, best practises, problems in the estimation
Project Manager	5	Tools and analysis used by the project function, overall project characteristics, best practises, problems in the estimation
Application Manager	2	Projects over 10 million euros in revenue and their specific characteristics
Project Coordinator	3	Tools and analyses executed by coordinators
Sales Support	3	Sales process, best practises, current problems and inconsistencies across sales function
Product Manager	2	Specifics of the case company's products
Controller	2	How costs are allocated and estimated for the products, KPI's of projects and sales functions
IT/ERP expert	2	How case company's systems are used, what problems are present in the current tools
Executive Vice President	1	How top management understands the uncertainty, what they lack in their decision making
Legal	1	Legal risks of the projects, management of these risks, tools and processes used for legal risk management
In total	**29**	

There was not overall question structure for these interviews, overall goal was to gather information about the process, different functions and their tools, how uncertainty was understood in general in the case company and what problems and issues there were in the case company. It was also necessary for the researcher to understand how the tools were used in the case company and what limitations these had as well as background information about the products and customers to completely understand the project environment. Even though the questions changed to each interview, notes were kept of these interviews and the main points were written after these interviews.

In addition to gathering information by interviewing people at the case company, researcher was given access to the notes and files of past projects, which provided also valuable information about past tools and techniques. This data also allowed to calculate significance of past cost overruns and old "lesson's learnt" files of the closed projects contained rich source of typical project failures and issues that was used to understand case company's projects.

Case company is Finnish high-technology company offering a wide variety of different products and services to its customers. Product offering of the case company is notably diverse, ranging from the small devices to customized system solutions. Furthermore, case company is serving customers in over 150 countries, and customers include both public and private entities and from the wide range of different industries. This mixture of wide product portfolio and customers then causes a high mixture of different sales channels and customer contacts.

This thesis focuses specifically on the project sales of the case company, which are large deliveries that are customized for the customer's needs. Also, if the delivery has high amount of risk or tailored services, it is considered as a project. Total volume is annually around 300 projects. Even project deliveries of the case company are diverse group of ventures since they range from small projects of tens of thousands of euros to large projects of millions of euros. Typical content of the projects varies a lot; while some projects focus exclusively on delivering one product type, others consist of bundles of different systems. Finally, projects can include multiple locations and project sites.

This causes significant uncertainties and variation to project deliveries. However, due to large product portfolio the cost overruns are quite balanced on the portfolio level. Especially the larger projects are interesting for this thesis, considering that the uncertainties and potential cost overruns associated with them are large as well. This was also acknowledged in the case company and the motivation for the company to participate in this thesis was to better control the larger projects and their costs. Other factor than size causing uncertainties is the global nature of delivery projects, as for example different local conditions, legislation, work cultures and taxation cause variation and unforeseen events in the projects.

6.2 Sales process of the case company

Project sales in the case company can be characterized as a long-term process of promoting case company's solutions for the customer. Sales process in the case company is divided into distinctive phases, and each phase ends with the decision-making gate in which it is decided whether to continue sales process and what actions are taken. Rough description of the sales process is presented in Figure 18.

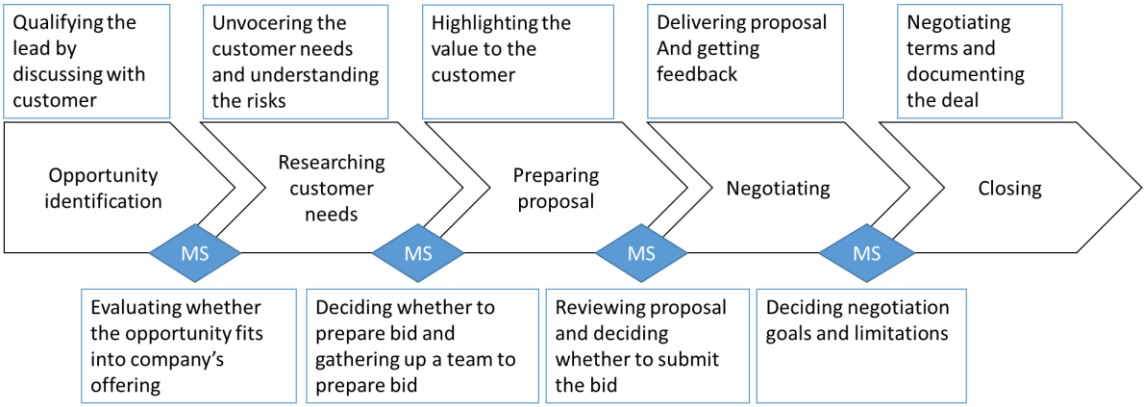


Figure 18. Sales process of the case company.

The beginning parts of the process aim to identify and influence the customer needs, whereas the latter part of this process is more about generating well-thought proposals and closing the sales deal. Quite typically the case company is responding to the open tender, so the specifications are quite strictly defined from the customer's side. However, also in these cases it is usually possible for the company to begin the discussions with the potential customer before the official request for quote is published. Case company also participates into cases where there is no public tendering process, and in these cases the sales can more freely specify the systems and solutions they offer for the customer.

Sales managers have the responsibility over the sales process, but they are supported by other functions of the case company. Most heavily involved in the supporting of project sales process is naturally the project function. Typically, it provides schedules, work estimations, technical support, evaluation of delivery terms and subcontractor analysis. Other typical support functions are product managers, who can provide sales with details about the product involved in the project delivery, for example what kind of modifications can be done for the product. When preparing the contract with the customer legal function supports sales by helping to draft or negotiate a contract where risks and rewards are balanced with customer.

6.3 Project delivery process of the case company

After the sales function has managed to close the deal, the case is handed over for the project function. This also means that specific project manager is named for the project that will oversee project execution. Project manager can sometimes be the same who supported sales in the sales phase, but this is not always achieved if that project manager becomes heavily involved into some other project during the course of sales process. The aim of the project delivery process is quite naturally to fulfill the customer expectations created in the sales phase as efficiently as possible. Even though the project planning has already started in the sales phase, it is up to the project function to finalize these plans, then oversee the execution and finally handle the project over to the customer and potentially to the service function, which may continue provide the customer with maintenance

and technical services associated with the products. Project delivery process is described in Figure 19.

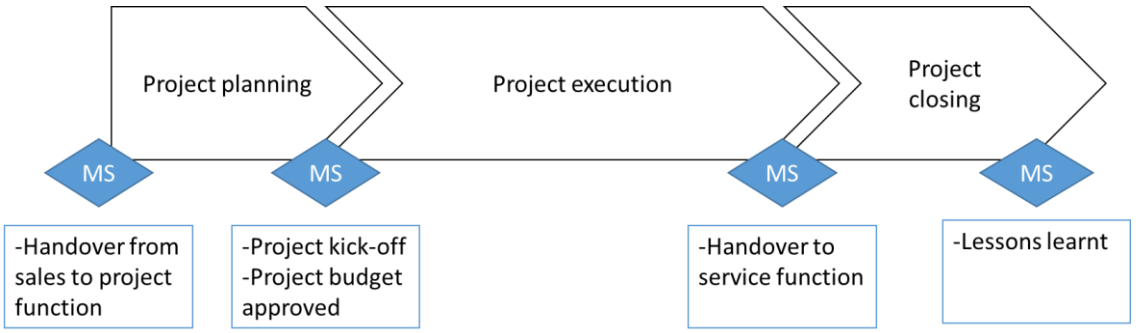


Figure 19. Project delivery process of the case company.

Handover to projects happens in the beginning of the project delivery process in a separate meeting with sales. In that meeting the goal is to share information about the sales case and interactions with the customer during the sales phase. This is a critical step in the process, as the sales function rarely continues to support project execution phase after the handover to project function is done.

Like stated in the Section 3.1., very often project planning is not finalized during the project front-end in the sales phase. This means that project delivery process starts by updating the budgets and creating the first forecasts of the project, as well as making technical planning for the projects. Even though it is preferable to have plans as ready as possible already in the sales phase, often customer's schedule or buying process does not allow this, and hence final subcontracting plans and technical specifications are often finalized in the project phase.

After project has ended and the open issues in the project have been resolved, final project meeting is held to document the lessons learnt and to analyze the project from different perspectives, such as financial, schedule and customer satisfaction perspectives. Sales function participates to this review as well to learn about the mistakes or successes that took place during the project execution.

6.4 Future plans and current issues

Recently case company has increased the sizes of projects it undertakes; instead of responding to requests to quote, the idea is to increasingly execute projects that consist of several sub-systems and proactively market these projects to the customers. This approach means significant increase in terms of project size, and while the case company has undertaken big system deliveries before, the size of 10-30 million projects it now actively seeks is something new. This increase of size of the projects has increased management concerns over the possibility of encountering significant project cost overruns;

these new projects are simply “too big to fail” compared to the overall size of the project portfolio.

In these larger ventures case company positions itself as turn-key provider, and has therefore increased control over the different aspects of the project. In contrast, previously in many of the past projects the case company has delivered its products to the integrator who is undertaking a bigger project for the end-customer. In these cases, case company’s project delivery has been just a small sub-project from the integrator’s and end-customer’s perspective. This model has sometimes caused communication issues with the end-customer, as there is other organization between the case company and the end-customer. However, working as a turn-key provider increases the complexity of the projects, as the case company is responsible from everything related to the project and not only about the delivery of its own products. This is the second factor increasing the concern of the management about the project cost overruns, as managing extensive subcontracting is not among the core competences of the case company and this often increases the risk associated with the delivery.

Proactive selling of these projects means that the customers do not always have clear idea of the project’s specifications, as they do when the project is sold through tendering. Customers might have clear needs, but as part of the sales process it is crucial to translate these into meaningful system specifications. Furthermore, the lack of initiative from the customer’s side means that they may lack procurement know-how and might not be fully aware what the system’s integration and deployment might require from their organization. These aspects increase the challenges of interacting with the customer and managing their expectations, and clearly communicating what is required from their side despite the use of term “turn-key”.

Case company’s tools and processes are not always tailored for project deliveries, as they have to serve other types of deliveries as well. Especially challenging are larger projects, as for example the cost estimation or quoting tools are completely unusable with the complexity of these new larger delivery projects. This manifests into usage of tailored excel spreadsheets, but their usage is dependent on the skills and tendencies of individual sales managers and causes unsystematic practices for cost estimates. Same goes for the risk management process, which has not been tailored to inspect the risk of large ventures.

Despite these challenges, the case company wants to continue to sell these larger deliveries from several reasons. First of all, they offer opportunity to establish intimate relationship with the customer and to tailor the offering exclusively for customer’s needs. Secondly, there is not many other companies capable of delivering these complex systems, which decreases the threat of competition in these larger cases. Finally, large projects also mean increased revenue, which is naturally interesting for any company seeking growth. The only issue currently therefore is the increased risk for cost overruns, and that needs to be minimized in order to continue successfully deliver also large turn-key projects.

6.5 Current cost and uncertainty estimation practices

Sales function is the main function responsible of forming the cost estimates for project sales. Process mainly takes place in the "prepare proposal" phase from Figure 18, but exceptions exist: for example, customers might want to have a non-binding budgetary quote in order to reserve adequate amount of money for their investment budgets, and in this case rough cost estimate is quickly prepared. The process for cost estimation includes often many other functions, such as project function, services, product managers and occasionally legal or financial functions. Despite of this, process can still be described in quite straightforward manner. The cost estimation process is presented below in Figure 20.

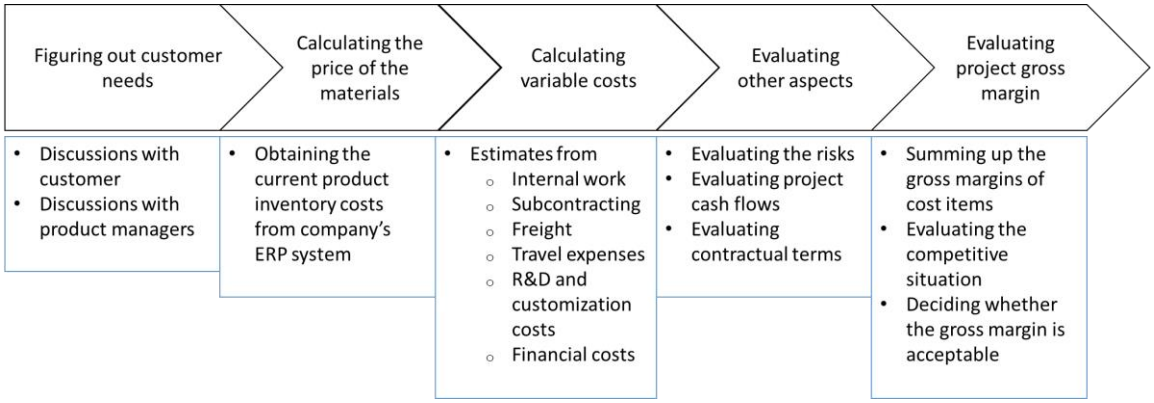


Figure 20. Case company's cost estimation process.

The process for cost estimates naturally starts from the solid understanding of the customer's needs, so that the "right project" is estimated. Often from the sales side this also requires discussions with the product managers to obtain the latest information what the case company can deliver. Estimates that are formed on the offering that do not match customer needs or that require heavy unanticipated modifications are common causes for major estimate error and later for cost overruns (Jackson 2002, Lee Jin-Kyung 2008, Shane et al. 2009).

Case company uses Enterprise Resource Planning (ERP) system, in which the quotes can be formed. The preliminary quote is usually prepared by obtaining the quoted items from ERP. The ERP contains costing and gross margins for different products, which are maintained by their respective product managers. This means that once the material and the hardware of the project is known, the pricing process is rather automatic for material components. In the case company, gross margin for products is sales price of the product minus its inventory price.

Variable costs, like work estimates, installation costs or subcontracting, cannot be obtained from the ERP. Variable costs are cost items that depend on many of the details of the project, for example from the target country, amount of customization that customer needs, available subcontractors, and local legislation. Current practice is that the sales

asks for estimates from the different functions that have the best capabilities to estimate these costs. For example, experienced project managers have quite vast amount of tacit knowledge about the amount of work that delivering certain system requires.

Subcontracting, such as civil works, can often form a big part of the project costs. Estimation of these is highly dependent on the amount of available information and the time available for estimation. In the simplest form and especially when the estimation process happens under time pressure, estimate can simply be based on the historical cost information of the same type of delivery to the similar region. When there is plenty of time to use for the estimation, quotas from the potential subcontractors are asked and the details of subcontracting are verified by visiting customer's sites where the project will be executed.

Finally, other aspects that can have the impact on costs of the project are estimated. These include risks, legal aspects and the cash flows of the project. However, the case company lacks culture where these aspects are regularly taken into account in the cost estimates; even though the risks, cash flows and contractual terms are (almost) always reviewed, only occasionally are these calculated into cost estimates. Therefore, the goal of the review is to determine whether risks are acceptable; there is currently often no middle ground option available where risks affect project costs. One typical example of the situation when risk is calculated in estimates is when the contract includes penalties from schedule overruns and the case company knows that it will be unable to deliver by the deadline. However, if the impact of risk, cash flow or contractual term is less clear, these are not calculated into the estimates.

After the content and the gross margins of the products and different services have been calculated, the gross margin of the whole project is evaluated to determine if it is acceptable and profitable for the case company. Decision makers know approximately the gross margin percentage that the project needs to have for the project portfolio to stay profitable on the company level. In addition, competitive situation is analyzed; when it is expected that the project is under heavy price pressure from other competitors, this might influence the target gross margin that the decision maker has in mind. The current amount of delivery projects has an effect as well; in the situation where the case company has more projects than it can deliver the gross margin is raised, and vice versa. This analysis might lead into some changes in project pricing and hence to the target gross margin that the case company aims for.

6.6 Current understanding on costs and uncertainty

One of the main purposes of immersing into the cost estimation activities of the case company was to find out what is the state of understanding on uncertainty and cost estimation in the case company. As the case company lacked the function for project estima-

tors, the practices regarding estimation and management of uncertainty were very versatile, as each project manager and salesperson applied a bit of their own methodology to the practices. While the main process and the ERP tool were utilized, it was common that both project managers and sales managers had their own tools for cost estimation, namely spreadsheets.

The reason for this was that ERP system was only designed to hold product and cost information, but it or any other tool in the use of company was not suitable for cost estimation. Spreadsheets were often very flexible and efficient tool for project sales, but their drawback was they were almost always personal copies and it was therefore difficult to gather detailed cost information in entirety. This caused situation where the cost information did not update automatically on these spreadsheets, causing instances where old cost information was used for estimation purposes.

It was not only the use of tools that was very diverse. The whole understanding about the cost elements used in the cost estimation process and furthermore the understanding over project uncertainty seemed to vary a lot from one individual to another. The main differences in cost understanding were spotted in the understanding on what gross margin and product inventory cost actually meant, and about the understanding on uncertainty level of the estimates found in the case company's ERP system. In similar manner, since the uncertainty was assessed in the case company only through crude top level risk review, the perception over the significance of uncertainty varied a lot. Top level risk process in this case meant that risk assessment had rough categories, but it was up to the sales manager to decide what he understood with for example "technical risks" and what was included in the analysis.

For individual products, the cost estimate is known as product inventory cost (PIC), which is available at the company ERP system. However, what many of the sales managers and cost estimators of the case company do not realize is that the concept of PIC that the case company is using does not equal the traditional business concept of "cost of goods sold" (COGS). This is because on the company level, the "cost of goods sold" contains not only PIC, but also project costs and "other COGS". This causes the gross margin on the company level to differ from the gross margin on the project level. This is illustrated in Figure 21.

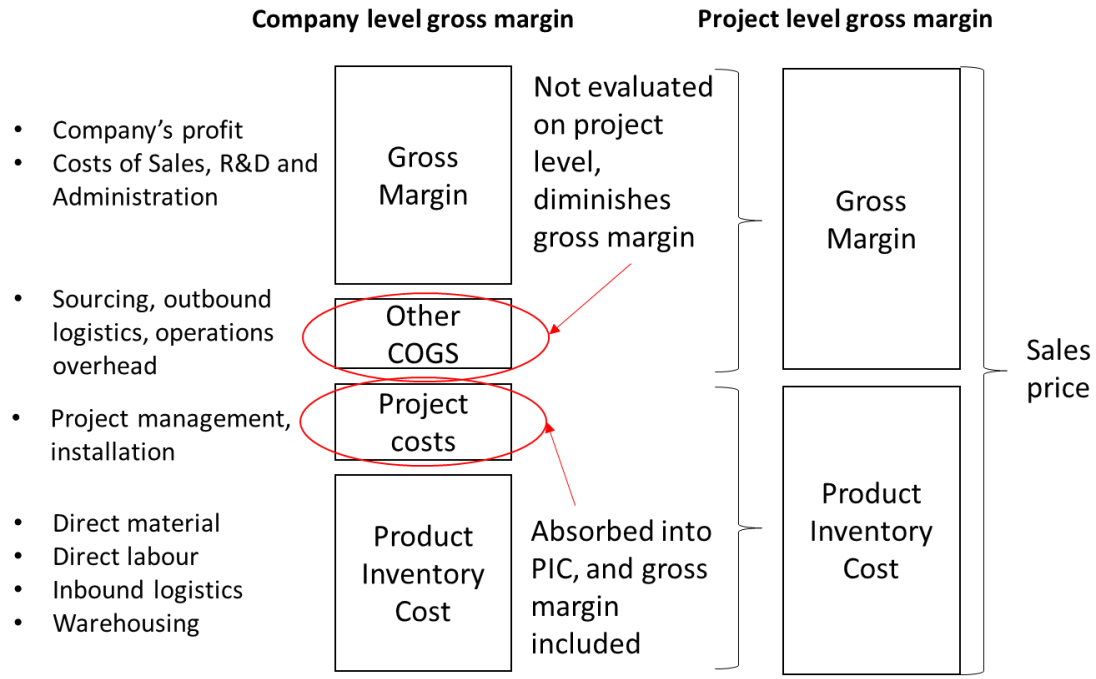


Figure 21. Understanding on project cost structure.

At the project level, term used about project costs is PIC. In the sales phase project costs are included in the PIC of the project, so they behave in a similar way as any material product. Other COGS in the company include for example overheads from sourcing or outbound logistics, which are excluded from the gross margin at the company level, but not at the project level. This causes discrepancies when analyzing project gross margin and comparing it to the company's gross margin: these numbers do not include the same things. Differences are typically around 5%, which is significant difference when analyzing project profitability, as that 5% can easily equal the amount of company's net profit from the project business.

This can also lead to logical biases when pricing the project items. While generally other COGS are only some percentages of the total project costs, there are items where they can be over half of the products sales price. On practice this means that when the sales manager is evaluating the pricing of the single items, he sees huge gross margins on these products, as the other COGS are not included. There had then been cases in the case company where this leads to the logical conclusion in sales manager's head that it is safe to give discounts from these items, while in the reality these products can be barely profitable for the company.

While the financial function was aware of this and its impacts, it was clear that the sales and project functions were not. It was also not clear if all the decision makers of the company understood what was included into different elements of the project costs at the project level and what impact this had on the company level. This leads to the bias among different organizational functions, as it seemed that the projects were being more profitable than they really were.

Similar biases were uncovered in the interviews regarding the work estimates associated with the products. Company's ERP system has templates that salespersons may use to form a new project quote for the customers. These templates also hold simple work breakdown on the task level and some values for these tasks. However, it was not at all clear for different functions what these estimates represented. While they were never used for actual, contractually binding quotes, sales managers sometimes used them for budgetary quotes or basis for negotiations. Among sales it was thought that these values were based on the historical data or the actual estimate about the amount of work it takes to deliver a product. In contrast, project function was not aware at all about these estimates and assumed that the work estimates were always to be asked from the project manager. Truth was that product manager created these estimates, and they were very crude estimates about the actual amount of work.

Uncertainty as analysis was not adapted systematically in different functions, as case company lacked the formal procedure for uncertainty management. Different actors were using mainly the lessons learned from the past projects to form a view on the uncertainty. The top-level risk management process of the company trusted a lot to the sales managers and their ability to recognize risks from the operating environment. Exception to this was the legal function, which had formal training and education over recognizing contractual risks and uncertainties caused by the vagueness of the contract.

If past projects were used as lessons learned, on the feelings on uncertainty it was often the projects that sales manager and project manager had participated that had the greatest impact on the project manager's perception on uncertainty. Especially the last project that the estimator had participated had an impact on how optimistic they were regarding cost estimates. In addition, the interaction inside the company and between sales and the customer were influencing a lot to uncertainty perception. For example, when the salespeople had long relationship with the customer, both parties adopted more optimistic views on the project's uncertainties.

Expertise gap explained well different perception on uncertainty. Each function emphasized the risks related to their area of expertise, and project function was the only one that had actual experience on dealing with the project risks. There were examples where sales had sold complex modifications to company's products without realizing the amount of work this would cause for the project function in the project implementation phase.

6.7 Objects and ends

When each function has different views on uncertainty, it is understandable that each function communicates and manages uncertainties regarding cost estimates differently. It turned out that current boundary objects used to convey information on project uncertainties were not suitable to produce a clear picture about the uncertainties regarding the project. Each part of the organization was holding its own pieces of information regarding

project risks, but these were not actively shared with other organizational functions. The case company did not have culture for incorporating uncertainty in the estimates. This was a bit surprising because, when discussing with different functions, concept of risk and risk for cost overruns were clearly recognized. However, when it was time to make cost estimates for projects, very deterministic, even optimistic view was adopted.

Some interviewees held the view that this was due the high variance in the company's projects. In majority of company's projects, it was acceptable approach to ignore the effect of uncertainty since the projects were so small that the effect of uncertainty on project portfolio level was insignificant. Furthermore, sales managers were often also responsible of selling instruments or systems – and when selling these the whole concept of uncertainty was unnecessary. In the larger projects this ignorance of uncertainty in the estimates and in communication could led to the situation where it was almost guaranteed that the project would overrun its budget since in these bigger deliveries something unexpected happened always.

When analyzing the ends of different functions, it can be seen that each function holds differentiating goals regarding project cost estimation. This created biases to the estimates and altered the information each boundary object possessed. For example, due the nature of their work and incentives, it was important for the sales to increase the amount of sales and to close the deal; this often lead to the temptation to give discount to the customer. However, decision makers of the company wanted to create pressure on sales managers for them to sell project with as good gross margin as possible. This then created incentive for the salesperson to be overly optimistic about different estimates in the project and disregard the cost of the risk. From different perspective, when the project function was responsible of estimating the costs, it wanted to add buffers so that it could ensure that it can deliver what was promised.

These examples do not represent all the members of these functions but describe well what kind of situations differentiating ends caused in the case company. Realistic cost estimation was not on anyone's agenda. These ends, objects and boundary objects between different organizations are summarized in Figure 22.

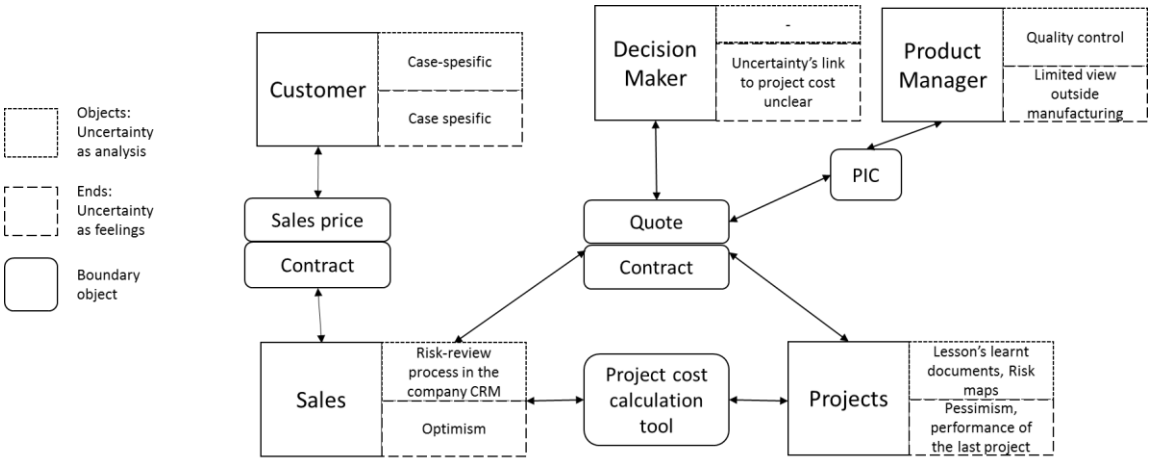


Figure 22. Objects and ends framework of the current situation.

In the figure above, it is important to note that boundary objects hold both information about the costs as well as from the uncertainties. Between sales function and the customer, the sales price is fixed, so the information on uncertainty is communicated through contract to determine what happens in the unexpected situations.

Project and sales were communicating about the cost estimates with spreadsheet tool, into which project manager estimated the amount of work project would require. This estimate was based on the personal viewpoint of the estimating project manager, so it was not surprising that these estimates varied a lot from project manager to another. This spreadsheet tool did not have any means to analyze uncertainty, so the only way to include that in the estimates for project manager was to add buffer. This then in turn created illusion for the sales manager that there was inefficiency in the project organization.

Sales, project function and decision maker were communicating cost estimates and uncertainty mainly with the contract and the quote, which had deterministic calculations about different components and their price on the project. Some sales managers understood that some buffer for uncertainties were necessary, so they included them into the quote. It was therefore impossible for the other functions to know based on the quote whether uncertainty was included into the cost estimation or not, and they had to trust to sales manager's words that the quotation calculation was in place and had enough buffer.

Finally, what was further complicating the things was again the concept of PIC. The responsibility to update these were at the product managers, but according to the interviews they were generally communicating changes in the PIC poorly. This meant that the changes in PIC were often surprises for the other functions. This led to frustrating situations for the sales and project managers alike, when the profitability of their projects would drop suddenly.

Objects and ends framework revealed the disintegrated nature of the case company's uncertainty estimation practices and very diverse viewpoints about the project cost uncertainty. It was therefore evident that there was a room for intervention in integrating these practices into more formal way of processing and analyzing uncertainty information.

7. INTERVENTIONS

7.1 External interviews

First intervention executed for the case company was a benchmark study of the uncertainty estimation practices in the Finnish project-based industries. The reason to categorize these external interviews as an intervention rather than information gathering is that the goal of these interviews was to gather best practices, tools and issues from the other industries and then to adapt this information for crafting the further intervention for case company's cost and uncertainty estimation process. Motivation for these was then mainly to fill information needs of the case company rather than fill gaps in the literature. Furthermore, these interviews provided the researcher with the expertise about the uncertainty estimation tools in use, which could be later used when championing for change and implementation of new uncertainty estimation tools in the case company. Practical sales and project managers are more interested to start using something when they hear that it is in use in other industries, rather than being just academic tool.

External interview questions were planned around four thematic topics: 1) Uncertainties associated with the project and the cost estimates, 2) cost and uncertainty estimation processes, 3) tools and methods actually in use for forming cost and uncertainty estimations and finally 4) best practices and issues that the usage of these processes and tools resulted. First theme provided the background of the projects and gave some understanding what interviewees understood with the uncertainty. Second and third theme provided actual methods for uncertainty estimation. Fourth theme revealed reality behind certain tools or at least the estimators view about practicalities of forming cost and uncertainty estimations.

As the case company's projects were complex ventures including elements of at least civil engineering, software engineering and machine deliveries, it was also natural to select the interviewed companies from different industries. In total 7 Finnish companies were approached, from which 5 answered positively for the idea of being interviewed for the research purposes. Method for finding interviewees was first to draft a short list of companies with a good reputation, and then through connections and cold calling reach the person(s) whose responsibilities include cost and uncertainty estimations for project sales phase. Finnish companies were selected solely because of their location in the same country with the main case company; this allowed the interviews to take place face-to-face and allow richer communication compared to the interview that would have happened for example via phone or email. The conducted interviews are presented in Table 7.

Table 7. External interviews.

Company	Number of interviewees	Profile of interviewees	Length of interview	Types of projects
A	1	Cost estimation engineer	79 min	Construction projects
B	1	Cost estimation engineer	53 min	Construction projects
C	2	Sales manager, Service manager	80 min	Software projects
D	2	Cost estimation engineer, Director of Project management support unit	80 min	Power plants
E	2	Project control engineers	75 min	Project consultants

As the idea behind the interviews was not to analyze each entity thoroughly, this thesis will not go systematically through each of the interviewed companies but rather focus on findings from those interviews. Interviewees themselves felt more at ease to reveal their practices and issues when they knew that the information they provide will not be traced into their specific company. Since the aim in this thesis is not to provide findings from specific company or from the specific industry, this thematic analysis of the interviews is justified.

Even though the external interviews had themes, these were not always followed systematically. In some of the cases the interviewees had concrete examples to show about their processes or tools in use, for example about their spreadsheets or software they used for estimations, and it made more sense to listen carefully the interviewees explanation of the usage of the tools and then increase the details with spontaneous specifying questions. However, during the interviews it was checked that all the themes were discussed through at some point. The example of the interview questions can be found in Appendix 1.

7.1.1 Uncertainties associated with the projects

Interviews started with questions about what kind of uncertainties interviewees associate with their projects and what are the causes of the uncertainty in their projects. Some uncertainties were clearly specific to the respective industries of the interviewees, such as the uncertainties of the soil in the construction projects or the impact of technology in the software projects. Despite of these industry specific uncertainties, responses had also striking similarities across different industries. The initial idea with the questions was to pinpoint uncertainties in the project environment, but it turned out to be that many of the uncertainties interviewees listed were uncertainties of the project's delivery process. This supports the notion from the literature that the uncertainty is often a problem of project management and that many times the external and internal reasons for uncertainties are linked (for example De Meyer et al. 2002).

First common element that the interviewees brought up in one form of another was control over the project and the estimation process. According to the interviewees, when the company has the control over the estimation process and the delivery project, there is less uncertainty. The logic was that when the company gets to plan the project on its own, it knows the solutions and decisions made in the planning phase and has greater degree of visibility over what is to be delivered.

Other element, which often was caused by the lack of control, was the lack of resources or rush with the estimations. According to the interviews, tight schedules were often to blame for inadequate estimates and hence caused uncertainty. When there was no time for proper analyses, it was impossible to know what uncertainties were associated with the project or to know how accurate the cost estimate is.

Third common element was the amount of detailed planning and design done for the project for which the estimates were based on. This is naturally linked to control and the schedule of drafting cost estimations: when there was not enough time to do proper study of the projects, the uncertainty was greater. Similarly, if the project plans were rigid and given from the customer's side or if the planning involved a lot of previously unknown stakeholders, the uncertainty with the estimates tended to increase. Logic can be summarized that the proper cost estimation requires good plans and drafts for the project, and the quality of these is affected by the time available and the amount information needed from outside the company.

7.1.2 Cost and uncertainty estimation process

Interviewees generally understood well the link between the uncertainty and the costs. As one interviewee stated:

> *"The most important task of uncertainty analysis is to recognize the elements causing uncertainty and therefore cost variation, and furthermore the situations and projects where our company is out of its core competence zone."*

The significance of project-specific knowledge and the continuity was strongly present in the responses. Many interviewees emphasized the significance of cross-functional cooperation and knowledge transfer as significant success factor of the estimation process. According to one interviewee:

> *"The best results [of meeting the project budget] are get when the team executing the project is involved already in the planning phase. Our company could increase its profitability by involving the project team more often in the planning phase."*

According to several interviewees, uncertainty in estimates can be reduced by increasing the amount of knowledge transfer and sharing between different functions, and when possible this should be done so that the project team responsible over the project execution

should also participate in the estimation phase. This was also present in the process of cost estimation, as most of them tried to involve the project team and other internal stakeholder functions into the planning process.

However, this was not always the reality in the actual estimation phase. The reason for not involving project team into the planning process was, again, often the rush and the project team being involved into the project execution phase. This simply meant, that the time of project manager and project team was allocated to the project only when it officially started, and they were often underused in the estimation phase. According to cost estimation engineer:

> *"Especially when there are many projects under execution, there is not enough participation from the project side to the estimation process. Even though our official process states that the project managers should participate in the cost estimation, it is not unseen situation where we submit a quote worth of millions without project manager spending a minute with the cost estimate."*

Apart from the cross-functional cooperation, the interviewees generally saw the estimation to include skills and functionalities specific for the cost estimators. Three of the companies interviewed had a separate organizational function responsible for drafting the estimates, and fourth was doing the cost estimations for other companies in the role of consultants. Only one company had the situation where the sales was the main unit responsible for drafting the estimates, and reason for this was perhaps the high degree of diversity of their projects – it would have been difficult for separate estimation function to gain enough know-how over the project to estimate it properly. Benefits of executing the estimates in a separate organizational unit were seen to be the more systematic usage of historical data and systematically executed estimation process.

Importance of including a several people to the process was emphasized. One company even used the amount of people who participated in the estimation process as a meter on how accurate the estimate could be expected to be. Apart from project function, the knowledge centered in sourcing, sales managers and different engineering units was valued. The benefit of including multiple people in the process was that the biases of one person or function tended to compensate each other out. As one cost estimation engineer said:

> *"Project managers are good people but they generally have perspective only for the last project they have been involved with."*

It is also noteworthy that the length of the process varied a lot even inside the companies. Some indicative estimation processes took some hours or minutes, and the most rigorous estimation processes could involve hundreds of hours of work solely from the cost estimator. People involved in the estimation also naturally increased as the desired accuracy increased.

7.1.3 Tools and methods for cost and uncertainty estimations

Contingency as a concept was used in all of the interviewed companies, even though the term in use varied. For example, some firms simply referred to it as "buffer" or "cost reservation". However, the methods for calculating the contingency varied greatly. Interviewed companies used fairly simple methods for cost estimation. For example, Monte Carlo analysis or any other form of cost simulation had been used only sometimes by one of the interviewed companies. Table 8 summarizes these tools used in the interviewed companies.

Table 8. Summary of the estimation tools in use.

Company	Method	Explanation	Tools	Person resbonsible for estimate
A	Variation analysis	-Each item was evaluated with three-point estimation -These estimates were used as a basis for calculating the cost distribution for the whole project	Spreadsheets	Cost estimation engineer
B	Multiple estimators	-Different estimators formed their own estimations -Through discussion consensus of the costs was reached	Spreadsheets	Sales
C	Risk mapping	-Risks and opportunities were evaluated in the risk workshop -Contingency was based on the cost reservations made for different risks and opportunities	Tailored cost-estimation software	Cost estimation engineer
D	Risk mapping	-Risks and opportunities were evaluated in the risk workshop -Contingency was based on the cost reservations made for different risks and opportunities	Tailored cost-estimation software	Cost estimation engineer
E	Using diminishing contingency	-Contingency diminished when plans and drafts for the project were improved	Spreadsheets	Cost estimation engineer

Estimates were not uniform, and their accuracy varied a lot. Most of the companies interviewed had a system where they drafted different kinds of estimates for different purposes. Indicative estimates were used as a basis for discussions with the customers, and final binding estimates were used as a basis of drafting the contract. For example, for early phases it was often enough to do crude parametric estimate and then only for the binding quotes do bottom-up cost estimate based on detailed project plans. Accuracy of the estimates naturally increased as the estimation effort and the detail of the project plans they were based on increased.

Request for quotes were important tool for the companies whose projects included a lot of subcontracting from other companies. This was the most practical way for these companies to get market price information and to ensure that the estimates for subcontracting parts are realistic. Interviewees also noted how asking estimates from multiple potential subcontractors increased the confidence to the estimate, especially if estimates of the subcontractors were close to each other.

All of the interviewed companies used some sort of uncertainty evaluation as the part of the cost and uncertainty estimation process, and the interviewees understood the link between uncertainty and costs. Risk side of the uncertainty analysis was generally emphasized. However, at least two of the interviewed companies also actively looked for opportunities that could affect into project costs in the sales phase. From interviewees' point of view, there was a practical reason for emphasizing risks, as one cost estimation engineer put it:

"Costs have tendency to be higher than expected rather than vice versa."

The way uncertainty mapping affected to the cost estimates however varied greatly. In the simplest form, the risks and opportunities were included into the project costs only as the sales manager's personal evaluation on how much risks project hold. More systematic way, found in the several interviews, was to go through categorized and mapped risks from the previous projects and then evaluate how these could affect the costs. This evaluation could be just again expert's estimate, actual cost associated with the project (for example contract penalty) or then analysis on the probability and cost impact of the event.

Historical data was used to varying degree. Almost all of the companies had a data bank from which they could look the realized costs of similar past projects. The exception were the projects that were based entirely on labor. Especially in the software projects these can be notoriously hard to estimate (for example Brooks 1995). Interviewees who used historical data saw it as important tool for accessing the most likely costs and getting objective information that did not include human biases.

7.1.4 Found issues and best practices

Issue that came up in several of the interviews was the tendency of estimators to adjust the cost estimates from the external reasons. This could happen typically in the highly competitive bidding situation or when there was internal pressure to present lower costs for the decision makers. Even though the interviewees might not always realize it themselves, this meant that in these situations the cost estimation and uncertainty estimate failed to deliver its most important task: to give a realistic analysis on the costs associated with the project. Especially in the competitive situations the cost adjustment was seen as a normal practice among interviewees.

Same problems could be found from the usage of the contingency. It was common method to base the contingency to fixed percentage or expert's evaluation; these methods lacked consistency and were therefore likely to convey false feelings of the accuracy of the estimates, as discussed in Section 3.5. Furthermore, these contingencies were manipulated to match desired results, which meant that these calculated contingencies did not quantify well the project uncertainty. As a positive note, the one company that had a systematic way of calculating the contingency also made sure it was not manipulated; rather, this company adjusted the sales price and the profit estimates in highly competitive situations.

The companies that used contingency reserves generally saw it as necessary element of the cost estimation. According to project consultant:

> *"There are always unexpected situations in the projects and without contingencies the project will almost certainly exceed its budget."*

Most of the times cost and uncertainty estimating requires a lot of assumptions, and these assumptions need to be documented if the organization wants to evaluate the accuracy of the estimate after the project has ended. According to the interviews, good documentation is necessary if the organization wants to learn from the estimates. In one interview organizational learning was raised as an issue. According to the cost estimator:

> *"The cost estimation unit is quite separated from the project unit, so the problem for us is to get enough information from the execution phase so that we can learn and improve our estimation processes."*

The impact of the sales KPI's to the successful estimates were also speculated in couple of interviews. The interviewees saw it generally to be better if the incentives of the sales are not only based on the amount of sales, but also the success of the projects. This would create an incentive for the salespeople to get realistic estimates. Problem in this model is that determining success of the project can take several years in some cases.

Sufficient resources were mentioned as an important antecedent for cost and uncertainty estimation success. Without these and the commitment of the management, the quality of the estimates is lower and therefore the inaccuracies of the estimates higher. The commitment and usage of time was also required from the other departments than the cost estimators, as the cost estimation was seen as a team effort.

7.2 Intervention for the case company's estimation process

Second intervention was to implement uncertainty estimation practices to the cost estimation process. Intervention started with a look into the company's past projects to determine the nature of company's cost overruns, as these would indicate the failures in the sales phase cost estimation. Data from the project profitability was available from the year 2009 onwards, and the sales phase documents were available with a little patience.

Cost overruns were visible in all the size categories, but especially striking numbers were met when looking into the 30 biggest delivery projects in the terms of revenue from 2009-2017. These numbers are presented in Table 9.

Table 9. Cost increases of the 30 biggest projects in terms of revenue of the case company 2009-2017.

All the projects		**Excluding the most profitable project category**	
Revenue decrease	-1.48%	Revenue decrease	-1.51%
Cost increase %	9.50%	Cost increase %	19.32%
Gross Margin slip	5.37%	Gross Margin slip	11.87%

The left side table includes all the 30 biggest projects. However, these projects included 10 similar projects for the same product category which content included mainly delivering material and a small amount of work; they were all highly successful and profitable. These projects are excluded from the right-side table.

As can be seen, the revenues tended to decrease and costs to increase in the projects, and numbers do not paint beautiful picture on the success of these bigger project deliveries. The costs had been estimated well below the actual level on the portfolio level, and of the 30 biggest projects 18 had exceeded their budget. When evaluating the whole project portfolio in the terms of gross margin slip, the result was annually usually around 2%. This fact was supported with the interviews in the case company where the larger delivery projects were seen more problematic than the others. From this point of view, it was decided that the intervention should focus on the bigger projects, as the uncertainties and cost overruns were more severe in this category.

Idea generation started with participating to cost estimation process for some of the case company's projects in the mid-October 2017. The idea was to evaluate different ideas on how the cost estimation team could evaluate uncertainty in the cost estimation phase and communicate uncertainties affecting to the cost estimation across functional boundaries. Ideas were based on the interviews both externally and internally, as well as to the existing methodologies from the project management literature. The ideas at this stage are presented in Table 10.

Table 10. Ideas for uncertainty estimation.

Idea	Explanation	Recognized issues with the method	Supporting facts	Source for the idea
Weighted average	-Estimating three-point estimates (best case, most likely case, worst case) for the cost items -Calculating weighted average	-Risk of estimating too low contingency	-Easy to understand	PERT-methodology (PMI 2008)
Probability distributions	-Estimating three-point estimates (best case, most likely case, worst case) for the cost items -Calculating probability distribution of the whole project based on these three values	-Difficulty to understand the concept of "probability distribution"	-Relatively easy to understand	-External interview
Monte Carlo analysis	-Estimating distributions for different cost items -Simulating the project to calculate probability distribution for the entire project	-Difficult to use and understand for sales and project managers	-Most accurate method for the estimation	-PMI 2008, external interview
Correlation	-As above, but in addition estimating correlation between cost items	-Difficulties to establish meaningful correlations -Difficulties to understand the concept of "correlation" for sales and project managers	-Would improve the model	-PMI 2008
Cost item contingency	-Adding contingency for the riskiest cost elements	-Difficult to document the usage	-Current practice in the case company	-Existing practice in the case company
Risk and opportunities review	-Going through uncertainties and assessing a cost and probability for them	-Difficulty to understand and estimate "probability" for risks	-Addresses the uncertainties that are not visible	-Interview with one of the project managers, External interviews
Historical data	-Using historical data to assess uncertainty for the project components	-Difficulty generalizing results for the future projects	-Produces quantifiable facts	-Interview with the decision makers of the case company
Project categorization	-Categorizing the projects and assessing the risks based on its attributes	-Difficulty of generalizing the categorization -Does not support decision making	-Easy to use	-Interview with the decision makers of the case company

The goal of the intervention was to produce a model for quantifying contingency for the projects that would correlate with the amount of uncertainty the project has. This model and concept of contingency as such would then act as a means to gather the known facts

and risks from different project stakeholders and work as a boundary object through which the uncertainty could be discussed. Advantage of contingency was that it was quantified, concrete number that provided information for the decision-making purposes. Figure 23 summarizes the goal of the intervention and the positioning of the ideas from the perspective of the framework of this thesis.

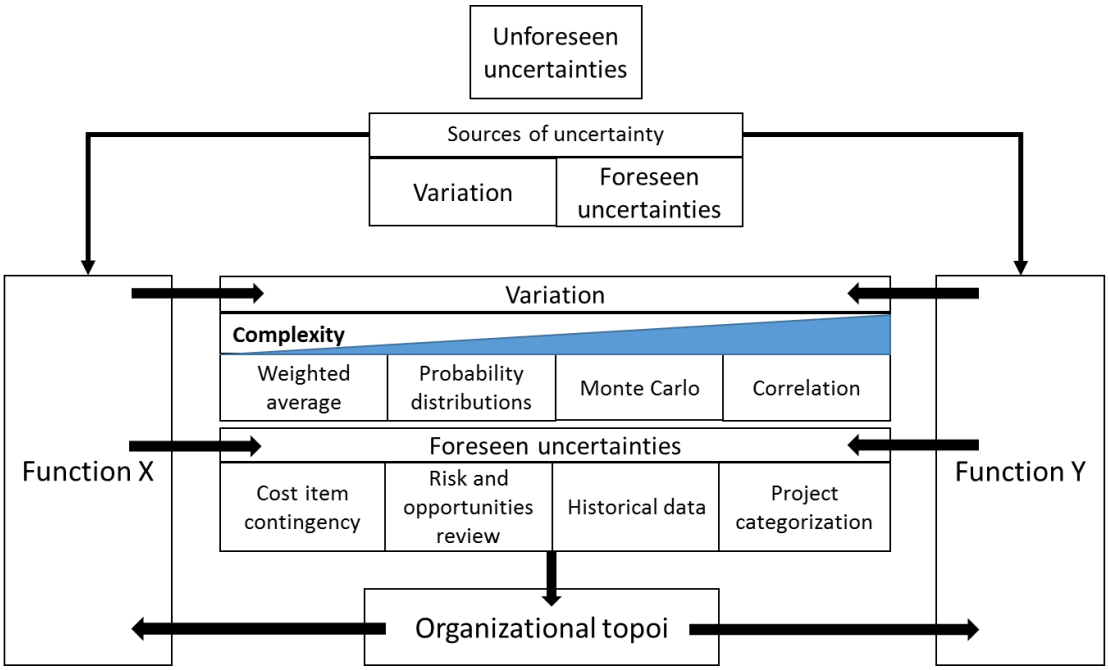


Figure 23. Positioning of the ideas to the thesis framework.

As can be seen from the figure above, first four of these ideas were more focused on recognizing variation from the estimated cost items. All of these four first ideas use three-point estimation as a source for data, which is a method of estimating three scenarios (best case, most likely case and worst case) for each of the cost items. However, complexity of these methods varies, simplest method being weighted average calculation and most complex Monte Carlo simulation with correlation. Last four ideas can be more associated with recognizing foreseeable uncertainties from the project environment.

Ideas were tested with sales and project managers to understand how they understood the tools. The cost estimation work in the case company for larger deliveries was done with MS Excel, so mock-ups for the ideas were developed in spreadsheet form in order to test the ideas and their suitability for cost estimation purposes. Testing itself was then session with the project or sales manager, where these mock-ups were used to estimate the uncertainty of the project.

When starting to test the tools, there were several criteria for the further selection and elaboration of the concepts:

1. Concept should help to recognize uncertainty in the project under estimation
2. Concept should be possible for the sales and project managers and other stakeholders to use and understand
3. Concept should allow justifiable quantification of contingency
4. Concept should enhance understanding and communication across organizational boundaries

Firstly, the cost of overruns could have been addressed by estimating equal contingency for all the projects, which would cover all the cost overruns. This would have effectively covered the costs, but this would not have given any supporting information for the decision making or helped to mitigate the effects of uncertainty for the specific project. Furthermore, case company had competition, so simply trying to put more costs and price on all the projects was not an option. This was the reason to aim for the concept that would help to recognize risks in the specific delivery project, as this would then allow the decision makers to mitigate the risks, exploit opportunities or to decide that the whole project is too risky for execution to begin with.

Secondly, the purpose of the tool was to support the work, collaboration and understanding of uncertainty while different organizational functions estimated the project costs. Therefore, ability to understand and use the concept was therefore important, as "black box" models for decision making could be dangerous for educated decision making in the long run. This criterion is of course highly subjective, as the stakeholders could be educated to understand more complex frameworks over time. In the context of this thesis, models that most of the interviewees could not grasp and understood during one-hour one-on-one session were deemed too complex, as there was less resources to be used for the actual implementation of the concept.

Thirdly, while the usability was important, the model should still be somehow justifiable and be based on facts, not just in the gut feelings. This was somewhat contradicting criteria with the second one, as any model building usually requires generalizations and abstractions (Hofstadter 1979). For the understandability and usability, crude generalizations were necessary, yet at the same time it was important that the complex reality was not simplified too much for the sake of simplicity.

Finally, the concept should increase cross-functional communication and aid decision making. Therefore, it was not enough that some model automatically produces result for the contingency – stakeholders and especially sales and project managers should closely participate to the uncertainty estimation. This arose from the simple fact that the sales

managers of the case company hold the information about the customer needs and realities, while the project managers were irreplaceable in their knowledge over actual deliveries and company's products.

7.2.1 Variance analysis as intervention

All the possibilities for estimating variation included doing three-point estimations, though the complexity varied significantly. The problem therefore was to select a method that had a right degree of both explanations ability and simplicity present. Monte Carlo analysis was also tested for the project cost calculation as a means to assign uncertainty. Difficulty here was that the concept was not simple enough for the stakeholders to understand, and hence the results did not really support decision making. Same was true for using correlations: attempts to include it in calculations made the whole estimation process too complex from the point of view of the sales and project managers. However, throughout the process of developing the ideas for intervention Monte Carlo was used to verify the approximations and to evaluate the risks of the projects independently from the sales and project managers.

The most promising ideas after different variations of simulation methods were the using weighted average and probability distribution, former for the simpler projects and latter for the large projects. The selected methods are illustrated in Figure 24.

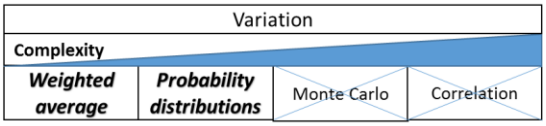


Figure 24. Selected ideas for estimating variation.

Before explaining the math, it is important to underline that the main point of the intervention was to increase communication through three-point estimation. This thesis does not aim to develop new methods for the risk calculation or approximation. From the mathematical point of view, there is a lot of potential for improvement in the methods. This is however true in any algorithm or abstraction; they rarely correspond to the complex reality. Aim was simply to cause the contingency to correspond the amount of variance sales managers and project managers expressed in their estimations; if they were sure of their estimates, different scenarios would be close together. However, when the estimates were pure guesses, the method would result in increased variance and increase the contingency for the project.

Process started by project stakeholders estimating three different cost scenarios for cost items: best, most likely and worst values. Best and worst represent values that stakeholders think the cost item might be if the worst risks or best opportunities realize, but with

the restriction that the scope of the project remains unchanged. “Most likely” is also generally intuitively understood term, and corresponds with the concept of mode from the statistics: the value that is most common in the dataset (Gujarati & Porter 1999). From these estimates the weighted average was then calculated, which for the decision making provided better estimate that corresponded to the average scenario of the cost items. This is illustrated in Figure 25.

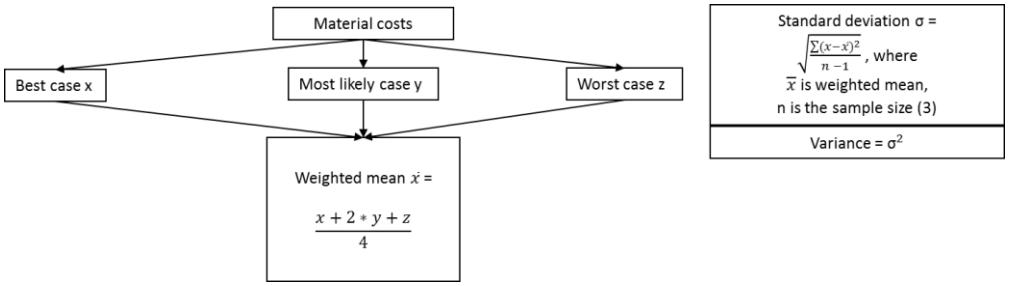
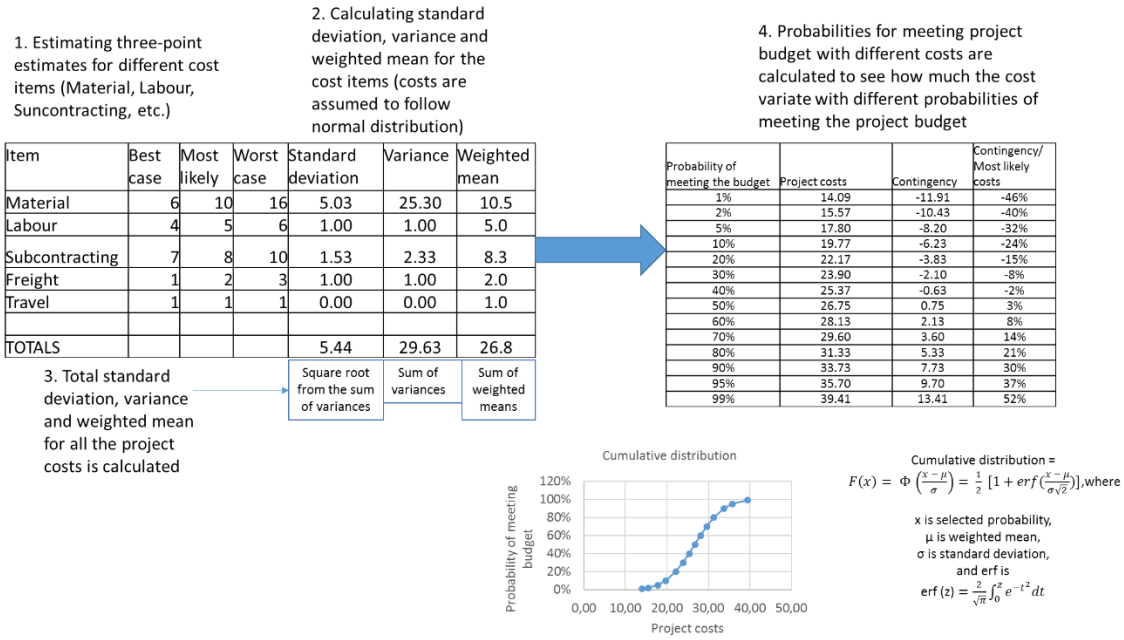


Figure 25. Example on three-point estimation.

The contingency that this estimation produced was then calculated by diminishing the sum of most likely values from the sum of weighted averages. Reasoning was, that the most likely values were the target values for each individual cost item. However, the weighted average was likely to be closer to the actual expenses on the project level.

Weighted average was enough for simpler and smaller projects where the efficiency and understandability of the uncertainty estimation were the main goal. Weighted average as a method was also very straightforward to explain, and therefore its usage was easy to sell for project and sales managers. However, for the more complex and large projects more complex version of this uncertainty estimation was developed which included evaluating the probability distributions of the different cost items. Even though weighted average already forced the stakeholders consider uncertainty related to different cost items, it was possible to end up with the calculation where different scenarios are far away from each other, but the contingency is still zero because worst and best case scenarios outweigh each other. To prevent this, evaluation of probability distributions was necessary.

For this, standard deviations and variances were calculated for the cost items, assuming them to be normally distributed. Based on these, distribution of the project’s total costs could be calculated. From these values the probability of meeting the project budget can then be calculated with the cumulative distribution. This is illustrated in Figure 26.



Item	Best case	Most likely	Worst case	Standard deviation	Variance	Weighted mean
Material	6	10	16	5.03	25.30	10.5
Labour	4	5	6	1.00	1.00	5.0
Subcontracting	7	8	10	1.53	2.33	8.3
Freight	1	2	3	1.00	1.00	2.0
Travel	1	1	1	0.00	0.00	1.0
TOTALS				5.44	29.63	26.8

Probability of meeting the budget	Project costs	Contingency	Contingency/ Most likely costs
1%	14.09	-11.91	-46%
2%	15.57	-10.43	-40%
5%	17.80	-8.20	-32%
10%	19.77	-6.23	-24%
20%	22.17	-3.83	-15%
30%	23.90	-2.10	-8%
40%	25.37	-0.63	-2%
50%	26.75	0.75	3%
60%	28.13	2.13	8%
70%	29.60	3.60	14%
80%	31.33	5.33	21%
90%	33.73	7.73	30%
95%	35.70	9.70	37%
99%	39.41	13.41	52%

Figure 26. Estimating cost variation with approximated probability distributions.

When using probability distributions, contingency was the amount of how much the project costs on selected desired probability of meeting project budget were higher than with just calculating the sum of most likely values. For example, typical desired probability for meeting the project budget was often 70%. This meant that there was 70% change of project costs being lower than the selected cost, and 30% change of the project costs exceeding the budget. Sum of most likely values was then extracted from this budget to calculate the contingency in the project budget.

Challenge when creating the method was to select desired level of accuracy for the cost items; if the three-point-estimation was used for all the smallest cost items in the project, this could result into hundreds of items that need to be estimated. However, spending time to analyze the cost variance of every single bolt and screw did not seem time well spent. Therefore, it was necessary to categorize the cost elements into meaningful categories that could be estimated in a meaningful way.

The advantage of this method was that it was easy to explain, as the 50% probability corresponds to the weighted average of the cost items, which as a concept was simple to understand. For smaller projects in the terms of revenue under intervention this 50% was enough; although method did not often produce significant contingency for these smaller projects, the simple act of estimating variance made estimate more accurate and reduced bias in the estimate. Because the model included also the means to assign higher probabilities, for strategical projects or projects in the bigger revenue category higher probability and higher contingency could be used.

7.2.2 Risk and opportunities review as intervention

Variation analysis could be used to estimate only the uncertainties that were visible in the cost estimation in the form of cost items. Therefore, cost overrun risks related to for example contractual penalties or into relationships with the customer could not be estimated simply by the means of cost estimation. Recognizing the potential cost implications of these foreseeable uncertainties required another method for estimation.

The idea for using of historical data as means to calculate contingency was scrapped. It did not enhance communication and it was impossible to apply historical information for specific projects, as representative and trustworthy data for project components was hard to obtain from the data sources of the company. Last but not least, types of the projects the company undertook had changed from the past, both in the terms of products and revenue, so over-confidence on quantifying risk from the past data had a risk of being counter-productive.

For the same reason, idea of basing the contingency calculation on categorization of the projects by their risk elements proved to be unsuccessful. While there was elements in the projects that generally meant increased risk and uncertainties, like for example size of the projects, amount of stakeholders and subcontracting and the type of the product, there was always exceptions whether these realized as cost-overruns. Furthermore, case company had tried categorizing projects in the past and the experiences from it were that it had been tool that had had little effect on actual project governance or pricing.

Many sales managers used system in the company where they assigned contingency for the cost items they saw risky, for example on the subcontracting in the cases where the company did not yet have binding deal with the subcontractor. This was tested as a tool to assign contingency for the items; however, the documentation of this practice became difficult, as it was under a dispute how much contingency should be assigned for certain items. Furthermore, in the cases where sales managers or project managers assigned contingencies for most of the project items, this created a lot of vagueness on the item costs and increased the contingency to the unacceptable level.

Therefore, second tool for the intervention was to compile a risk register from the past projects, that could be used as a basis for discussions between project stakeholders. Actual intervention for the company was to teach to sales and project managers how this register could be used to recognize risks and opportunities from the project environment. The selected idea is highlighted in Figure 27.

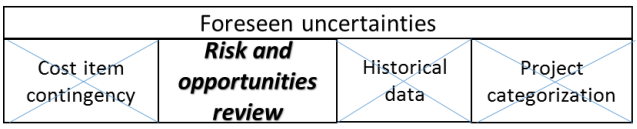


Figure 27. Selected idea for estimating foreseeable uncertainties.

Currently the case company had a risk review process; however, the aim was to answer whether the risk was unacceptable, not to the question on the financial implications on the risk. Furthermore, the company lacked the formal process of reviewing possible risks systematically before the quotation phase.

In addition discussing about the risk and mitigation actions, in the risk and opportunities review project stakeholders' purpose was to also discuss the financial implications of the risks by assigning probabilities and costs for the risks. Contingency would then simply be the multiplication of probability and cost, and overall project level sum of all these individual contingencies calculated for different uncertainties. Register also contained typical mitigation actions that were suitable for the risks. This register is illustrated in Table 11.

Table 11. Example on risk review.

Risk	Propability	Cost	Contingency	Mitigation actions
Technical failure	10%	5,000.00 €	500€	Quality control
Descoping	5%	-	-	Contract modification
Relationship with integrator	10%	-	-	Steering group
Data communications	25%	100 000€	25 000€	Survey
	.		.	
	.		.	
Contractual penalties	20%	200 000 €	40 000€	Survey

Challenge with this was that people understand probability in a different way, and different stakeholders have different opinions on how much risk can be mitigated. Therefore, it is crucial to understand that the contingency here is the expert evaluation on how much contingency should be used for specific risk. This means that different parties agree about the size of the contingency, and often the number can be questioned. However, going through the risks documents the viewpoint and the current understanding on their severity, which improves the situation over ignoring all the financial implications of the risks and opportunities.

7.2.3 Putting pieces together

The presented pieces of intervention were both components of contingency that was then added to the cost estimate of the project and treated as a part of project costs. Goal of the variance analysis was to recognize the uncertainty from different cost components of the project. In contrast, risk review process was specifically aimed for recognizing foreseeable uncertainties that could be recognized from the project environment by different project stakeholders. This is illustrated in Figure 28.

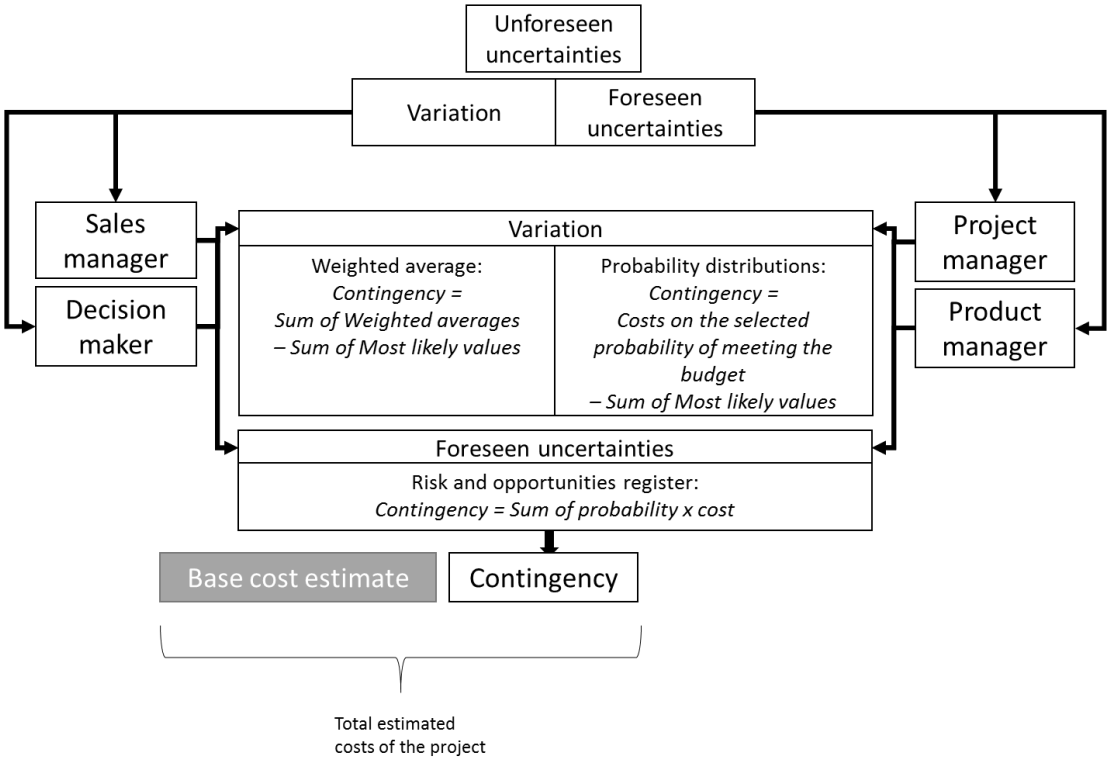


Figure 28. Elements of contingency.

As can be seen, the intervention did not take into account unforeseen uncertainties. This was mainly because the unforeseen uncertainties are something that cannot by definition be countered with deterministic methods. Therefore, their mitigation was mainly possible only in the project execution phase with the actions of project manager. However, the amount of contingency was recommended to be rounded up as it was common knowledge that not all the uncertainties can be estimated.

Contingency that was calculated did not disappear anywhere at the end of the sales process. It remained in the sales phase documentation and was stored to the company's ERP system to be used for lessons learnt exercises in the future and to be critically evaluated whether contingency had been sufficient on portfolio level. Unfortunately, none of the projects whose contingency was researched during the intervention did not end, so any data from the calculated contingencies correspondence with the reality was not collected during this research.

Literature also recognizes the possibility or even encourages to analyze contingency during different stages of the project (Lorance 1992). This would then communicate the development of uncertainty during project execution phase. In this intervention this was not incorporated as a part of forecasting activities for project managers, mainly because administrative work was already seen too high among the project managers and because the risk analysis from the cost perspective was not seen as a tool supporting decision making after the sales had been made. However, implementing contingency evaluation in the different life stages of the project remains possibility in the case company especially for critical and strategic projects.

7.2.4 Implementation of the method

The concepts developed in cooperation with the sales and projects were also implemented to the usage. Hence, during January – February 2018, the implementation of the uncertainty estimation process took place for the cost estimation process. The implementation consisted of following elements:

1. Modifying case company's project cost estimation spreadsheets so that they used variation analysis and had a risk and opportunities register
2. Presenting the idea for the company's regional heads and other key decision makers
3. Testing and selling the method by participating to 1-3 test cases in each region
4. 5 separate training sessions for case company's project managers from different regions
5. Documenting the usage and instructions for the tools and sharing them with the case company

Firstly, the case company's tools, especially spreadsheets, were modified so that they included the idea of variation analysis and risk and opportunities review. Case company's "project cost calculation tool" had an established structure for different cost items that were to be evaluated for project cost calculation. This was modified so that the tool included different cost scenarios (best, most likely, worst) by default. In addition, past risks were added on the separate sheet to be used as a basis for the risk and opportunity reviews between sales and project managers in the future. For larger projects a modified version of these was developed, as there was more need for ad-hoc estimates and a need for the estimator to decide themselves the adequate level of accuracy in the estimate. Furthermore, for these larger projects the concept of probability distributions was included.

Secondly, the idea was presented for the case company's key decision makers to gather feedback and to sell the concept for them. Issue that the key decision makers had was the math behind the model, which confused some of them. They argued, that simpler models were better and more time efficient to use. This feedback was taken into account so, that the especially for the main bulk of projects that were estimated in the case company

weighted average method was recommended, and the more sophisticated estimation with probability distributions was reserved for the larger project deliveries.

Thirdly, the concept was tested again with projects from different regions. Reasons for these tests were to both gather feedback and through familiarizing the concept for the sales managers, project managers and decision makers to sell the idea and its benefits. These tests were necessary to ease the internal struggle between project and sales functions about the estimation and especially to alleviate the suspicion of some of the decision makers towards the method. After the tests, the decision makers were receptive towards the concept as they had seen the methods in use and had a change to give feedback.

Fourthly, five training sessions were organized for the company's project managers in different regions to teach the usage of the method. One of the interesting things countered in this phase was the difficulty of some project managers to understand the concept of "scenarios". This was true especially for the project managers from outside Europe, as they were expecting some strict guidelines on what the "best" or "worst" scenarios should be. The idea that they were free to estimate these based on the project characteristics seemed alien to them. There are many plausible explanations for this behavior. Maybe the projects that these managers undertook were more "standard", i.e., they had less variation. Other possible explanation that crossed researcher's mind is cultural differences. There were of course differences also among Finnish project managers on their ability to analytically estimate different scenarios or even the project themselves based on the available data and experience these project managers had. However, these differences were especially underlined when training project managers from different regions and cultures.

Finally, instructions of the methods were written and shared with the case company. Unfortunately, the training for the sales managers was rather thin and limited to different practical tests that were undertaken with sales. Case company's project function had intention to slowly implement the concepts to the practice through project managers who used the concept. If the concept proved to be successful also in longer practice, the sales managers who were especially focused on the project sales could then be trained for the concepts at some point in the future.

8. DISCUSSION AND LESSONS LEARNED

8.1 Results of the intervention for company processes

Sales function saw that the contingency was something that was increasing the sales price, and this was often their feedback on the concept and basis of their reluctance to adopt the concept. However, contingency as a concept is not linked to the sales price; it is linked to the cost of implementing the project, and contingency should be treated as a separate concept from the sales price. This was not understood by everyone in the beginning of the intervention. This was true also in the project management where contingency was seen as a magical tool that would make project automatically more profitable. Figure 29 illustrates this point.

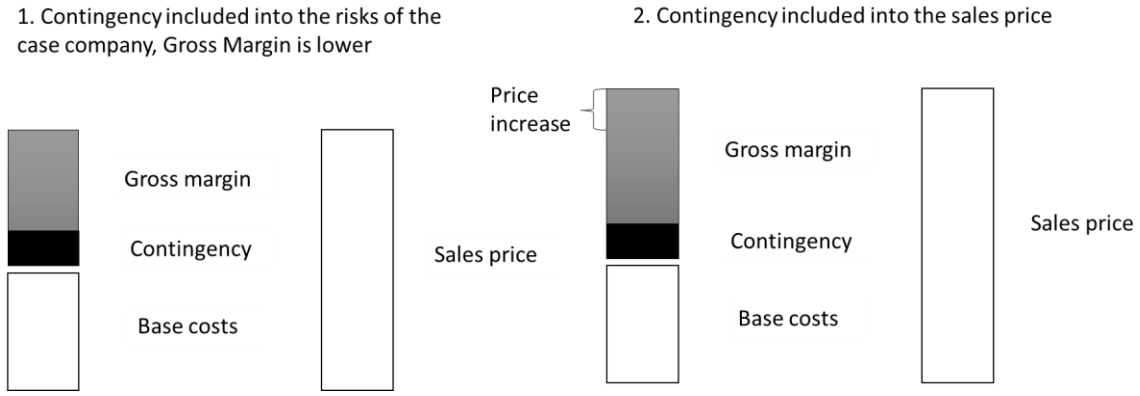


Figure 29. Effect of contingency into the Sales price and Gross Margin.

As Figure 29 illustrates, in these kinds of projects where the supplier company is calculating contingency for tender purposes, whether or not to include the contingency into the sales price is a business decision and this decision should not affect the size of the contingency in any way. However, attitude to manipulate contingency according to the business situation was often present in different discussions. When thinking further, idea that risks somehow disappear or opportunities appear according to how many competing suppliers there is or how much money the customer is willing to pay is clearly absurd. It remains vague to which degree these encountered bias were deliberate attempt to get managerial approval for the project and to which degree simply misunderstanding of the contingency as a concept.

Second objection especially from the sales function was that the project execution was already taking too many resources; therefore, contingency would allow them to be more inefficient. This argument might be true to some extent; like Baccarini (2005) notes, the

contingency which is too high might cause sloppy project management. This is not however sufficient argument to claim that no uncertainties and contingencies exist in the project environment and to create unrealism in the cost estimations.

Third counter-argument for the method is related to the position of the researcher in the case company. This intervention was executed for the project management function, which caused the issue of some sales managers seeing this as the project management's unnecessary attempt to disturb and control the sales process. In short, the researcher fell initially to victim of not-invented-here syndrome, which is the negative attitude of respondents towards knowledge that was externally invented (Antons & Piller 2015). Therefore, even though it was generally acknowledged that the knowledge sharing is important for the successful cost estimation, at the same time sales function felt strong ownership of the sales process and felt that the sales manager should be responsible of crafting all the estimates.

As a result of the intervention, the emphasis for risk management and communication of the risks moved from the project planning phase to the quotation preparation phase. In the sales phase it had been necessary to "understand the risks" before the intervention. This was done by categorizing risk on very high level and then sales manager's responsibility was to mark that they had gone through the risks and contact and review the risks with other stakeholders if necessary. However, what this meant in practice varied a lot: in some cases, it might mean rigorous risk review session, in other cases simply sales manager's personal judgement that the risks were under control. Typically risk management plan was then executed at the start of the project; the result of intervention was to systematically start this management of the risks already in the sales phase. This is illustrated in Figure 30.

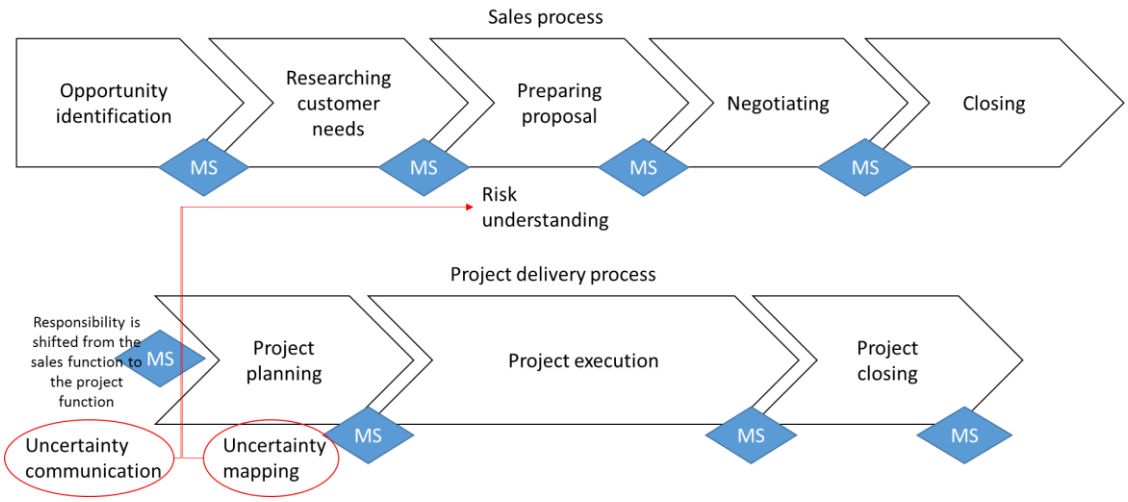


Figure 30. Shifting the emphasis of uncertainty analysis to the sales process.

Risk review and variance analysis acted as the boundary objects between key organizational functions, projects and sales. Intervention did not change the way these functions

internally analyzed uncertainty as analysis and as feelings. Sales function preserved its inherent optimism, and project management kept its pessimism about the project performance. However, the intervention enabled these functions to communicate these feelings and their analyses. It is also worth to note that the longitudinal aspect of this study was quite limited, and therefore it would have been interesting to see the long-term effects of the intervention to see whether the attitudes towards the uncertainty would change permanently. Updates to the company's objects and ends framework are presented in Figure 31.

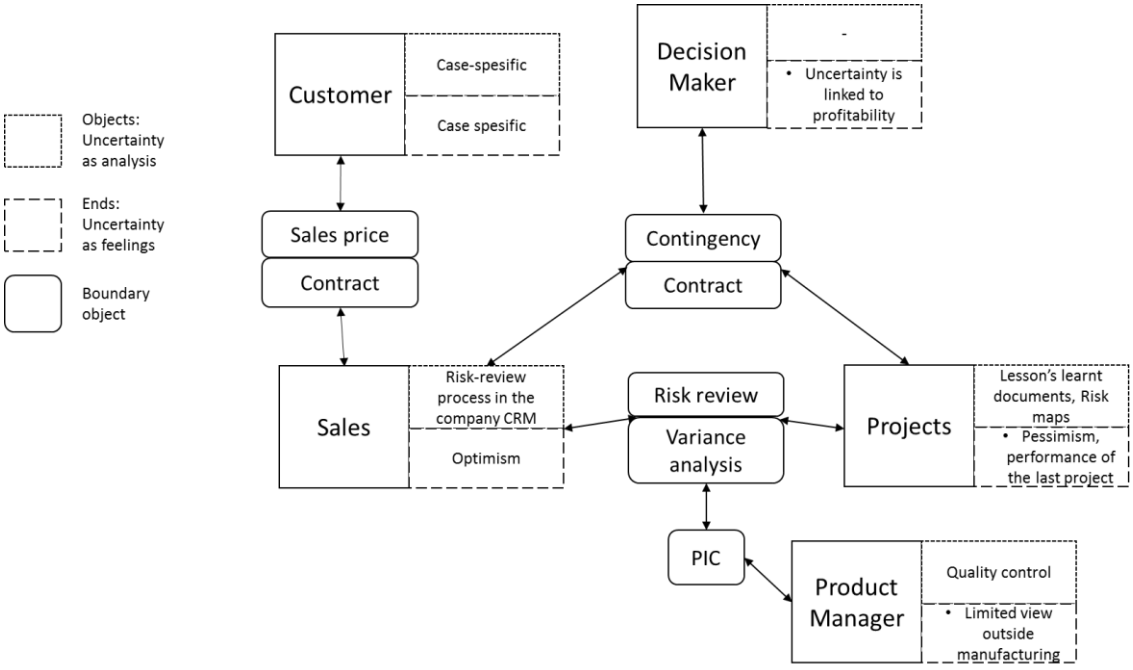


Figure 31. Knowledge boundaries and uncertainty management in the case company.

Contingency acted as a boundary object between projects, sales and decision maker on whether to pursue the project or not and what actions should be taken in the form of uncertainty management. Previously, uncertainty was managed in many boundary-object-in-use, while after the intervention boundary objects for uncertainty management were designated boundary objects, following the taxonomy of Levina and Vaast (2005). Communicating uncertainty in the forms of risk review and variance analysis enabled more complete picture on the issue. Risks had been discussed before in the decision-making process, but usually the focus was on the most evident risks rather than reviewing the risk portfolio as a whole.

Contingency also crystallized for the decision makers the linkage of uncertainty to the profitability. Previously its analysis had not been done in a clear manner when reviewing quote: uncertainties were discussed from the viewpoint whether risks were acceptable, but the analysis on whether the gross margin is good enough if some risks realized was omitted.

Variance analysis allowed to include the potential changes in material costs and therefore product prices, which was omitted as well in the previous process. Previously, when the material prices changed, they were updated to the company's ERP system. The possibility of them changing was not taken into account during the sales process, even though it might take years from the quotation until the project would start. To make things worse, the product managers did not seem to communicate these changes much outside the formal ERP process. Variation analysis allowed the project cost estimation team to also include these changes into the analysis, and potentially to even inquire from product managers whether they should expect significant increases on product prices in the upcoming years.

Situation towards customer remained unchanged; the sales function was the main link towards the customer during the cost estimation phase and therefore had the best knowledge of the customer needs. Contingency was not communicated towards the customer, as they also were not aware of the internal cost structure of case company's products and labor.

8.2 Results of the intervention compared to framework

After presenting the results of the intervention, it is now possible to evaluate the intervention against the framework presented in Section 5.3. This intervention considered uncertainty analysis as boundary object, through which different organizational functions can communicate to overcome organizational boundaries. This framework and intervention's position in it is presented in Figure 32.

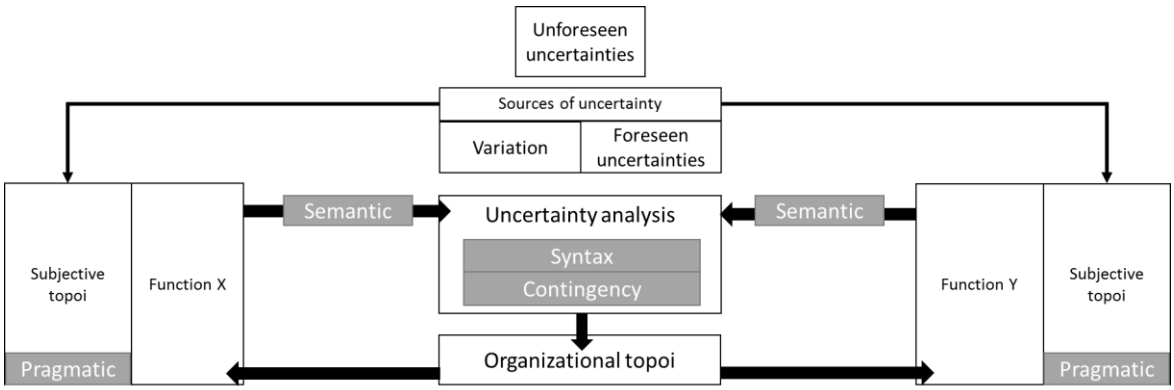


Figure 32. Intervention compared to framework.

Framework can seen from the viewpoint of Carlile's (2002) knowledge boundaries of syntax, semantic and practical boundaries. Contingency creates a syntax through which different project stakeholders can communicate their views on uncertainty, both analytical and their feelings about the uncertainty. In turn, each actor's subjective topoi can be seen to contain what Carlile (2002) mentions as pragmatic knowledge boundary: motivational and political boundaries. In turn, semantical boundaries are present when different

actors and organizational functions communicate their viewpoint on uncertainty. These semantic and pragmatic boundaries can then be overcome with the help of contingency and the syntax it creates.

Classification of variation and foreseen uncertainties proved very useful and the parts of the intervention, variation analysis and risk and opportunities review, were built to correspond into these types of uncertainty. Uncertainty analysis does not analyze project environment as it is, but the information from it goes through different project functions where it is assessed through their subjective topoi: objects that they use to analyze uncertainty, and their ends and feelings they have towards project uncertainty. This then conceptualizes function's perception on uncertainty, which is then communicated through the designated boundary objects.

This analysis constructs the shared perception of uncertainty, or organizational topoi, as different stakeholders' perceptions are communicated and constructed through boundary object of uncertainty analysis. Even though internal perceptions on uncertainty of different functions do not change completely during the process, this shared perception documents how different parties see uncertainty. Contingency as a concept proved to be very efficient way of doing this, as it is quantifiable number and puts a price on the risk, which makes the business impacts of uncertainty visible.

Finally, this shared perception on uncertainty can influence over time the internal perceptions of different functions and cause organizational learning. For example, if the analysis and communication lead to the conclusion that there are significant risks for example regarding subcontracting, this might cause different participants to evaluate subcontracting costs and uncertainties more critically in the other projects as well.

Uncertainty as a boundary object offers a clear look on how different organizational functions can use boundary object to facilitate conversation and make sense of the uncertain project environment. None of the actors know complete picture of the project environment alone, and most of them have some sort of biases in their perceptions of uncertainty; truth is probably to be found somewhere between different extremes. Boundary object enabled this conversation.

Furthermore, boundary object also gathered known facts about the uncertainty. Without it the pieces of information could maybe have been found from the quotes, contracts and other relevant project artefacts. While using these boundary-objects–in-use was often enough to pinpoint major flaws and risk, they were not enough to support decision making about the uncertainty as a whole. Contingency as a boundary object offered clearly communicated analysis available on the uncertainty.

8.3 Reaching the objective of the thesis

In the introduction it was highlighted how there is a gap between theoretical and practical sides of project uncertainty management. To narrow this gap, the goal of this thesis was to investigate, how organizations estimate, make sense and communicate uncertainty and its costs in the project sales phase. To support this goal, three sub-goals were determined. Interviews and interventions that were conducted offered insights into this topic.

8.3.1 Analyzing uncertainty

To root the research into the optimization school of project management, the first supportive goal was to map the ways and methods actually in use for performing uncertainty analysis. Therefore, the objective was to find out what kind of tools are used to estimate uncertainty in Finnish project-based industries.

It is worth to note immediately in the beginning that the sample used to answer to this objective was inadequately small – 6 Finnish project-based companies in total, one of which was analyzed thoroughly as a case company. That said, in-depth interviews and case study analysis provided more concrete and deep insights about the practices of these companies than for example a questionnaire would have had.

The first and surprising finding for the researcher was to realize the absence of uncertainty estimation tools in the case company itself. Sure, everyone who dealt with the projects understood the fact that there was uncertainty in the project environment, but either they did not use any systematic measures to deal with uncertainty or then they had their individual practices to respond to this uncertainty. Organization therefore lacked systematic way of analyzing uncertainty in the sales phase.

More importantly, the inability to link uncertainty to costs was other takeaway from the original "tools" that were at place in the case company. Practices that were sometimes used at the case company, like high-level risk review or risk mapping, did not bother to ask, "how much can this risk portfolio cost to us?". This is understandable from the viewpoint that these tools were often utilized only after the project had already been sold, after which the goal was of course to deliver the project with the lowest possible overall cost.

Findings from externally interviewed companies can be summarized as follows:

- Contingency was often used concept, but not always properly understood
- Communication and multiple estimators was emphasized as a key component to successful estimation
- Used tools were fairly simple
- There was emphasis on expert judgement

Firstly, externally interviewed companies all had the concept of contingency at place, but it can be argued based on these interviews that in these companies either the link between uncertainty and the costs was not systematic or clear. Some of these companies admitted, that they manipulated the contingency based on the "competitive situation". This of course lets the contingency have its task as a buffer, but it is not anymore an analysis of the uncertain environment or expectations like Venkataraman & Pinto (2011) or Baccarini (2006) argues contingency should be. Uncertainty does not magically disappear when there's more competition in the market.

Secondly, communication and use of multiple estimators was often emphasized. This makes sense from the point of view of the framework of this thesis: since every function and individual has their limited view on the external project environment, the estimation model that relies on only one individual is doomed to be biased towards the analysis and feelings of this estimating function. Through communication these viewpoints and feelings they can be brought closer together and more realistic (but not always unbiased) cost estimate can be formed. This is also probably an explanation why for example practices like alliance model are becoming more common in the projects where multiple stakeholders are included; it might not be enough to communicate internally for the best estimates.

Thirdly, the tools in use were fairly simple in most of the external companies interviewed. Simulation models or different types of algorithms were not widely used in these companies. Considering the wide variation of different approaches to estimate and optimize the projects that are available in the literature, this seems to support Söderlund and Maylor's (2012) conclusion of the research gap between hard and soft sides of project management literature. It seems at the light of this thesis that the project organizations need more knowledge of the effects and support for actually implementing different estimation methods that literature suggests.

Finally, as a result of fairly simple methods there was emphasis on expert judgement. Statistics of the past projects were incorporated into the cost estimation system, but for other information and especially for the contingency expert judgement was often the basis of estimate. Reason for this according to the interviews seemed to be the "uniqueness" of projects and the environment, from which only the human mind is best to make estimations and assumptions. However, the growing evidence suggests that in many estimation and forecasting situations simple algorithms often win human estimators in accuracy (Meehl 1986). Project management literature still seems to lack researches that would compare the human ability and algorithms ability to estimate project costs and uncertainties, or in which the algorithms and human's capabilities are combined. Considering the hype around artificial intelligence and machine learning, there seems to be a dire need for this kind of research.

8.3.2 Impacts of the intervention

The second supportive objective aimed critically observe, what are the implications that the intervention caused were in the case company. Therefore, the aim was to observe, what impacts the implementation of uncertainty management tools has for a case company that does not have previous experience about estimating uncertainty.

Thorough the whole thesis and especially during the intervention there was a very profound conflict between projects and sales present, which can be traced to the inherent optimism of the sales function and inherent pessimism of the project function that was observed in the case company. This conflict meant that during the intervention the main "adversary" for the proposed methods was the sales function and the main "champion" for them was the project function.

All the functions had previously thought about uncertainty and did the best they could individually, but the organization lacked the formal definition for "uncertainty". As Slovic (1987) stated, the definition of risk is not something objective that is out there in the real world; therefore without a common language these organizations also lacked means of discussing about the uncertainty. Boundary object solved this problem and contingency acted as a tool through which different factions could communicate their view on the uncertainty. It acted as a common syntax between the functions and demonstrated for the organization that there is a link between uncertainty and project costs.

Contingency as a concept for the first time allowed the organization to start to collect data about the "buffer" included in the projects. Previously there had been contingency-like elements in the project budgets, but they were not documented. This meant that after the project start no-one in the case company could tell the assumptions that had been used for calculating price for some elements or if the probable cost overruns were taken into account. This allows the organization to critically evaluate the calculation method of contingency in the future, as the calculation method can be easily changed even if the contingency as a concept remains.

Contingency as a concept forces the organization to take the uncertainty into account already in the sales phase; without this concept it was easy for the organization to completely ignore the analysis of uncertainty for the projects. There is still risk that the contingency is manipulated or that it is calculated in a wrong way in the organization, but at least it is now acknowledged in the organization that the projects have uncertainties, and that the uncertainty has cost effects that already require attention in the sales phase.

However, biases or the subjective topois of the different functions did not disappear. This also meant that conflicts between different viewpoints remained. This is not necessarily a problem, as the whole idea of the framework is to facilitate communication and integration. However, it is necessary to acknowledge that sometimes simple boundary object or

concept is not enough to solve communication problems, and if the conflicts really lead into biases in decision making the communication and interaction needs to be facilitated also through other means than through the boundary object.

Long-term effects of the intervention are still missing from this thesis. At the time of writing this the implementation of the method continued for different regions; there also seemed to be interest from smaller system business side to familiarize itself with the concept to deal with the uncertainty in the project environment. It would be interesting exercise from both personal viewpoint of the research as well as from a point of view of this thesis to visit the case company in a couple of years to see what developments the concept takes after the intervention.

8.3.3 Enhancing common understanding

Third supportive objective was more rooted into the behaviorist school of project management research. The aim was to tie the results of the uncertainty analysis to what was happening in the project organization by figuring out and observing how uncertainty estimation tools can enhance understanding and communication about project uncertainty.

This question was answered through the framework of boundary object and more precisely through the framework in Figure 32. Uncertainty analysis acted as a tool that allowed different functions to construct their views on foreseeable uncertainties into actionable analysis. Through this analysis different functions could construct more shared perception about the project uncertainties.

This case example has shown concretely how necessary it is to integrate different actors' subjective perspectives, topoi, to gather together facts and to support decision making about project uncertainty. Without defining the elements of uncertainty and analyzing the most crucial aspects of it, it is impossible to manage uncertainty. Furthermore, if different actors continue to operate with their own perspectives on uncertainty, the actions of the organization are not aligned. In practice this might mean for example situation where sales function is giving considerable discounts to the sales price because they believe gross margin to be safe, and at the same time project function is estimating costs too high because they see considerable risks in the project execution.

On more general level, framework in Figure 32 can be applied to Norreklit et al. (2006) work on subjective realism. If framework is taken out of the context of project uncertainty analysis, it is also valid in describing how different actor's subjective topois are integrated to organizational topoi through the usage of boundary object, which gathers together different foreseeable facts. This is illustrated in Figure 33.

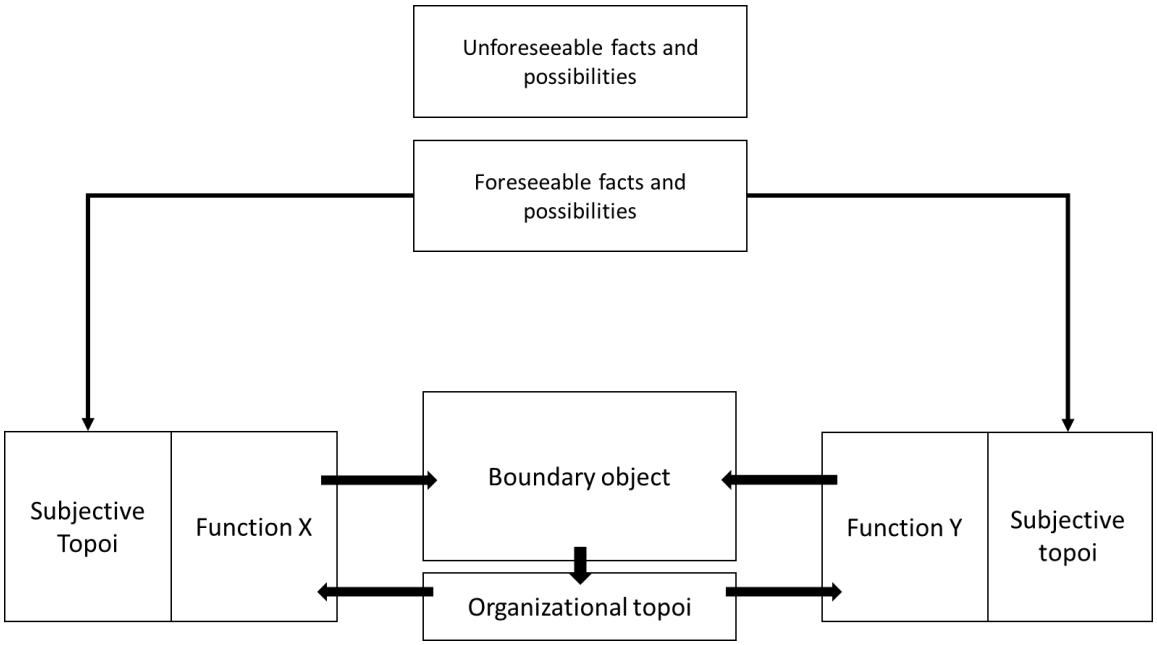


Figure 33. Building organizational understanding.

This is in line with Laine et al. (2016) findings where the concept of boundary objects was applied to product development. This case study shows that the similar fact constructing is necessary also when analyzing project uncertainty. Contingency offers a syntax and allows the view on uncertainty to be translated into monetary terms. Furthermore, the clear linkage to different types of uncertainty – variation, foreseeable and unforeseeable uncertainty – is key finding of this study.

Boundary objects are valuable tools in enabling communication, but from the analytical perspective they also have their limitations. Communication through boundary objects remains subjective and can only take into account the facts and subjective topois of different actors who participate into the process. Therefore, this thesis does not claim that groups of experts estimating the project costs are the superior method for cost estimation because it is very likely that this is not always the case (for example Meehl 1986, Kahneman 2011). However, communication of the different viewpoints and common syntax seems to enhance understanding of the project uncertainty, even though if the superior estimation method for different remains to be proven.

It can be argued that this fact constructing through communication in project management is valuable in itself. In many other occasions when humans are engaged in the estimation or prediction activities, they do not have any more control over the results. This is the case for example when investment bankers forecast future stock prices; they do not control the results. However, in project business, the project manager and the organization is responsible for the execution of the project during the execution and is therefore in the position of affecting the cost. While it is certainly possible to improve the forecasts with statistics, data and algorithms, this research also seems to point out that the understanding

of the project environment is valuable information for project and sales also for project management and execution purposes.

This causes the need to balance between practicality and the quality of the analysis. For all the parties to understand the results and for the analysis to successfully convey information, result needs to be understandable for all the participants. Unfortunately, this also can mean that it is necessary to sacrifice complexities and details of the analysis, like happened in this case. Researcher in this case would have loved to analyze uncertainty through Monte Carlo analysis and take into account correlation, but unfortunately this would not had increased the understanding of the sales managers and project function if they do not understand the analysis.

Therefore, one goal of the uncertainty estimation process can be defined as transforming unforeseeable uncertainty to foreseeable uncertainty. While the fact remains that everything in the project environment can not be analyzed it is also true that if the uncertainty is analyzed sloppily then more facts will remain unforeseen for the organization. This process requires that project managers and the organization have better understanding of the uncertainty after the analysis. Good communication and usage of different functions' strengths minimizes the amount of facts that remain unforeseen during the cost estimation process.

This thesis offered a concrete example on how different types of uncertainty recognized by De Meyer et al. (2002) and Van de Heijden (2011) can be analyzed from the project environment. While literature for project environment offers myriad ways to perform uncertainty analysis from risk mapping to neural networks, literature rarely acknowledges that different types of uncertainty might need different analysis methods.

Thought of different types of uncertainty having an effect on how uncertainty is managed is generally available in the literature; De Meyer et al. (2002) work also ends up with this conclusion. Other well-known example is the CYNEFIN framework developed at IBM (Kurtz & Snowden 2003), which aimed to help managers recognize the type of uncertainty of the phenomenon to be managed, so they can adapt the management of the project accordingly. However, in both works the starting point is recognizing the type of the project as a whole, not categorizing different elements of the project to different uncertainty categories.

However, the idea of analyzing different types of uncertainty with different methods for forecasting and estimating purpose seems rare in previous literature. For example Project Management Body Of Knowledge only discusses about estimation (PMI 2008), and articles in the optimization school of project management are often mostly interested about developing one estimation method. Closest to this though are Garvey et al. (2016) with

their systems engineering perspective, acknowledging that uncertainty needs to be analyzed on the different levels of the system. This definition roughly corresponds to the thought presented here.

8.4 Research weaknesses and mitigation efforts

According to the Golafshani (2003), the three essential measures for research are validity, reliability and generalizability. In quantitative research, reliability can be defined as the consistency of the results, so that the similar research setting would produce similar results in the future. Validity refers to the ability of research to offer evidence for its results. Generalizability means ability to extend the findings from the specific research to wider population.

However, in qualitative research, which this case study represents, this is not that straightforward. As Stenbacka (2001) notes, whereas in quantitative studies the purpose is often to explain, in qualitative studies it is to understand the situation. According to Stenbacka (2001), perfect reliability in qualitative study is irrelevant, as it is impossible to repeat qualitative study reproducing people and the setting. Similarly, it is impossible task to proof in qualitative context that study is valid; instead often the term validity in qualitative context refers to the rigorousness and trustworthiness of the research (Mishler 2000). This also means that many qualitative researchers give low priority altogether to generalizability (Schofield 2002); for example Denzin (1983) sees every qualitative study to carry its own "logic, sense of order, structure and meaning".

However, even if the terms validity, reliability and generalizability fit poorly to the qualitative research as such, this does not mean that the quality of the research could not be controlled and increased in qualitative studies. While it might not be able to generalize findings to the population as a whole, it can still be possible to generalize the findings from this thesis roughly to similar settings as in this study (Johnson 1997). Johnson (1997) proposes several common strategies to promote the validity and quality of qualitative research. These are presented in Table 12.

Table 12. Strategies to promote qualitative research quality (Johnson 1997).

Strategy	Description
Extended fieldwork	Researcher collects data over extensive period of time
Theory triangulation	Use of multiple theories for explanations
Investigator triangulation	Use of multiple researchers
Method triangulation	Use of multiple research methods
Data triangulation	Use of multiple data sources
Participant feedback	Discussion and feedback gathering with the participants of the study
Peer review	Discussions of the conclusions with the other people, especially with another researcher

Negative case sampling	Looking for cases that are not aligned with expectations and other results of the researcher
Reflexivity	Self-awareness and criticality about own biases

Triangulation has been presented as one central way of ensuring good quality, trustworthy and rigorous qualitative study (Golafshani 2003). For example Golafshani (2003) encourages its use in order to control bias and justify proposals, but also notes that it might not be sufficient or suitable for all the research settings. Nevertheless, if different settings and different people produce similar results, this increases the generalizability of the results (Johnson 1997).

Noting that the generalizability, validity and reliability as concepts has been questioned altogether in qualitative research, some more detailed general weaknesses considering especially this study could be recognized:

- Starting point of the research where the goal of the research is to improve case company's processes
- Researchers immersion in the daily activities of the case company and exposure on biases at the case company
- Interventionist research approach and the possibility for idiosyncratic results (Suomala & Lyly-Yrjänäinen 2012)
- Behavior of the interviewer might affect answers of the respondents (Saunders et al. 2011)
- Nature of the qualitative research in general and its lack of objectivity (Golafshani 2003)
- Difficulty of isolating the variables and the existence of other potential solutions (Hancock et al. 1998)

Several of Johnson's (1997) strategies to increase the quality of this research were utilized during the process. These are presented in Table 13:

Table 13. Used mitigation strategies.

Strategy	How strategy was applied
Extended fieldwork	The research took place for six months in the case company's premises, communicating daily with the project management practioners
Theory triangulation	Multiple theories (Boundary object, Uncertainty, Project management) were used. However, each of these were used to solve a specific piece in the phenomena, and multiple theories were not used to proof the conclusions
Participant feedback	Feedback from the proposed solutions were constantly asked from participants. Study and its conclusions were supervised by the project management director at the case company.

Peer review	Study and its conclusions was read by another student and supervised by professor
Method triangulation	Usage of multiple methods (intervention, semi-structured interviews)

Mitigation efforts to reduce these weaknesses are presented in Table 14:

Table 14. Mitigation of the specific research weaknesses.

Research weakness	Mitigation efforts
Starting point of the research where the goal of the research is to improve case company's processes	Topic of the research was not influenced by the case company
Researchers immersion in the daily activities of the case company and exposure on biases at the case company	Documentation of the discussions at the case company in a form of research diary.
Interventionist research approach and the possibility for idiosyncratic results (Suomala, Lyly-Yrjänäinen 2012)	External interviews; Peer review
Behavior of the interviewer might affect answers of the respondents (Saunders et al. 2011)	Interviewees knew about the topic of the interview and the main points of interests, so they could prepare for topic
Difficulty of isolating the variables and the existence of other potential solutions (Hancock, Ockleford & Windridge 1998)	Interrupting several project managers and sales managers workflow with the intervention and evaluating the practicality and worth of the solution

Case company provided the rough outline for the thesis topic; that is, the topic of project cost overruns. However, decisions after that to where to head the research was decided by the researcher. The theoretical frameworks of this thesis were also not interesting for the case company; rather from its viewpoint the results, better communication and quantification of the risks, were the main outcomes of this thesis work.

Fundamental weaknesses of the qualitative method could not be mitigated. While it can be stated that this thesis represents sufficient quality and trustworthiness for qualitative scientific research, it remains a possibility that other explanations can be offered. While the concept of boundary object at the light of this research seems like a powerful tool to manage and enable uncertainty estimation process, other frameworks or tools for though could have proved similarly good results.

9. CONCLUSIONS

This research was exploratory, and its main purpose was to observe the changes that happen in the organization that implements uncertainty estimation practices. Main contribution of this research is to demonstrate in practice that the concept of boundary object is powerful tool in facilitating communication of uncertainty in the project cost estimation phase. Through this communication organizational topoi, perception on the project uncertainty, can be formed by translating the views of different organizational functions into cost implications. Moreover, the tools used for the uncertainty analysis should be clearly linked to the different types of uncertainties in the project environment, and they should be understandable for the participants and the executioners of the cost estimation process to promote their usage and to enable them to be used meaningfully in the decision making.

This thesis adopted a view of uncertainty as a construct. Considering that the project does not yet exist, and that uncertainty is by definition something, which current state is not known, this is only meaningful approach to the topic. Uncertainty transforms from the construction to reality as project progresses, and therefore the accuracy of the estimate can be researched after the project execution. Research of this learning process was omitted here and could be a fruitful research venture because it is not trivial how to communicate the estimation errors to the original estimation team and how their behavior changes as a result of this communication.

This thesis did not build new knowledge about what psychological biases are in play in the project front-end management; instead, it presents concrete example on how different project stakeholders topoi can be brought together to justifiable analysis through the usage of boundary objects. Researching these biases and how they are communicated in broader perspective would be interesting for the further research. Difficulty in this kind of research is to extract the variable: it is hard link specific bias into certain behavior. One concrete way to overcome this could be to compare the human estimations to estimations of different algorithms.

This thesis was conducted from the viewpoint where company internally estimated the cost of a project for sales phase quotation. It would be interesting venture for further research to bring external stakeholders, such as subcontractors and customer, to the estimation process. Knowledge boundary between the company and external stakeholders would be especially challenging to cross. However, recent developments for example in the alliance model projects (Van Marrewijk et al. 2008) also suggests that researching communicative tools for these types of ventures would be very interesting.

For managers, this thesis underlines the need to integrate different functions also for the estimation purposes and to understand that the estimations are social constructs, not absolute and objective statements of the project reality. In this thesis the system to facilitate conversation was boundary object of contingency. In the situations where there is separate cost estimation function, the methods and analysis for the cost estimation can be more complicated and therefore all the functions do not necessarily need to understand process of the analysis. Nevertheless, the need to involve different viewpoints to the estimation practices remains. In these situations, boundary object could be something that is understandable for all of the stakeholders even if the analysis itself is outsourced for a separate function.

From the uncertainty management perspective, this thesis also underlines the importance of connecting uncertainty and costs. Even though this is common practice in literature (PMI 2008), the external interviews and the case company revealed that this is not always done in practice. This is understandable from the viewpoint that assigning cost to risk is usually based on very subjective analysis, which was one of the issues that arose during the intervention. Therefore, the estimators might feel that it is wrong to put price on something that can not be measured and is not real. However, the fact remains that uncertainty during projects causes delays and cost overruns, so this thesis recommends putting price on uncertainty even when it can not be accurately estimated or calculated.

From the practical perspective, this thesis offers a good model on how to estimate different elements of uncertainty for tender purposes. It is important to be able to define the project in the terms of meaningful cost elements, which variation can then be analyzed. After this, the uncertainty that is not related to the cost items needs to be treated separately to prepare any cost implications those elements might have. Finally, these analyses require sufficient amount of time and the communication between stakeholders is especially crucial for the project success from the cost management perspective.

Against project management literature this thesis provides a practical example that there is still a research gap between analytical methods and individuals and organizations practical understanding over these developed methods. More research and examples about the implementation of the methods and changes in organizational behavior and knowledge would be beneficial for the project management field. Moreover, during this research many biases and limitations of the humans to predict future were encountered. Understanding of the project environment is crucial, but at the same time increased knowledge and more sophisticated estimation methods would benefit project cost estimation. It would be beneficial to research practical implications of different estimation methods, algorithms and processes and how these can support human decision making.

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APPENDIX 1. EXTERNAL INTERVIEW QUESTIONS.

Background information

- Please introduce yourself and your position in the company shortly.
    - How your current role and previous role are linked to the project cost estimation?
- What kind of projects your company executes?
    - What is the product?
    - What is the success criteria?
    - What are the most important stakeholders?

Project uncertainty

- What kind of uncertainties are typical for your projects?
    - What are the root causes of these uncertainties?
- What are the causes of cost overruns?
- How can the uncertainty be managed before the start of the project?

Cost and uncertainty estimation process

- How do you estimate uncertainty before the start of the project?
    - How is uncertainty estimated during the project execution?
- How do you estimate project costs?
    - What is the official process for project cost estimation?
    - Who are involved in the process?
    - How does the customer, subcontractors and other stakeholders participate in the cost estimation process?

Tools and methods for project cost estimation

- What data you use for project cost estimation?
- What tools do you use for cost estimation and uncertainty estimation?
    - Why do you use these tools?
    - What are the benefits of these tools?
    - What shortages and issues these tools have?

Best practises and issues

- What kind of practical problems there is in cost estimation?
- What kind of new methods have you considered for project cost estimation?
- What are the requirements for successful project cost estimation?
- How do you think the uncertainty should affect price of the project?

At the end

- Do you still have something else in your mind, which is related to the project cost estimation or uncertainty?